NAVY BEAN PRODUCTION SYSTEMS IN MICHIGAN

By

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ABSTRACT

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IN MICHIGAN

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With the development of the new high-yielding upright navy bean variety (Swan Valley), it was believed that its productivity could be further improved by using different production management systems. Two navy bean varieties, Swan Valley (upright) and Fleetwood (standard), were tested to determine the yields and header losses under two different row spacings (70 cm and 35 cm) and two harvesting methods (conventional and direct).

A mixed-integer linear programming (MILP) model was developed to come up with the appropriate decisions as to which navy bean variety to plant (Swan Valley or Fleetwood), planting system to follow (wide rows or narrow rows), harvesting method to apply (direct or conventional) and machinery set to use in the production.

This study also considered the impact of having two mixed crop systems (navy bean-corn and navy bean-sugar beet) on the farmer's profit in Michigan. Mixed-integer linear programming models were developed to find the most profitable crop to produce under the fluctuation of the

Ghassan Al Soboh

crops' market prices, the profit to be made under different percentages of a mixed-crop system, and the machinery set to contribute in each production system.

The model results indicated that the upright navy bean variety, Swan Valley, planted in 70 cm rows spacing and harvested directly was more profitable than corn. While sugar beets were found to be the most profitable crop.

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Major Professor

Approved ______________________
Department Chairman

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TABLE OF CONTENTS

LIST OF TABLES v
LIST OF FIGURES viii
LIST OF SYMBOLS ix

CHAPTER

1 INTRODUCTION 1
1.1 Basis of the Problem 1
1.2 Literature Review 4
1.2-1 Harvesting Practice--Developments 4
1.2-2 Machinery Selection Model Approaches 12
1.3 Objectives 15

2 METHODOLOGY 18
2.1 A Mixed-Integer Linear Programming Approach (MILP) 18
2.2 Model Assumptions 20
2.2-1 Tillage System 20
2.2-2 Weed Control 23
2.2-3 Fertilizer Applications 25
2.2-4 Planting Systems 31
2.2-5 System of Cropping 34
2.2-6 Insect and Disease Control 34
2.2-7 Harvesting Methods 35

3 DATA COLLECTION 41
3.1 Navy Bean Production 41
3.2 Corn Production 44
3.3 Sugar Beet Production 46
3.4 Field Machinery 50
3.5 Machinery Cost Model 52
3.5-1 Model Description 52
3.5-2 Model Results 57
3.6 Power Requirements 57
3.7 Predicting the Number of Suitable Days for Field Work 64

4 NAVY BEAN PRODUCTION MODEL 79
4.1 Model Formulation 79
4.2 Model Adjustments 94
4.3 Model Results 95
4.4 Sensitivity Analysis 98
4.4-1 Shadow Prices and Slacks 98
4.4-2 The Cost of Forcing Nonoptimal Activities Into the Optimal Solution 101
4.4-3 Range of Optimality 103

TABLE OF CONTENTS (continued)

CHAPTER

5 NAVY BEAN-CORN PRODUCTION MODEL 106
5.1 Model Formulation 106
5.2 Model Adjustments 122
5.3 Model Results 123
5.4 Sensitivity Analysis 123
5.4-1 Shadow Prices and Slacks 123
5.4-2 The Cost of Forcing in Nonoptimal Solution 125
5.4-3 Range of Optimality 126
5.5 Testing Different Percentages of Bean and Corn in the Navy Bean-Corn Production Model 129
5.5-1 A 75 Percent Bean-25 Percent Corn Production System 129
5.5-2 Model Adjustment 132
5.5-3 Model Results 133
5.5-4 A 50 Percent Bean-50 Percent Corn Production System 133
5.5-5 Model Results 138
5.5-6 A 25 Percent Bean- 75 Percent Corn Production System 138
5.4-7 Model Results 140

6 NAVY BEANS - SUGAR BEET PRODUCTION MODEL . . 143
6.1 Model Formulation 143
6.2 Model Adjustment 160
6.3 Model Results 162
6.4 Sensitivity Analysis 162
6.4-1 Shadow Prices and Slacks 162
6.4-2 The Cost of Forcing Nonoptimal Activities into Optimal Solution 166
6.4-3 Range of Optimality 168
6.5 Testing Different Percentages of Navy Beans and Sugar Beet in the Navy Bean-Sugar Beet Production Model 171
6.5-1 A 75 Percent Sugar Beet - 25 Percent Navy Bean Production Model 171
6.5-2 Model Adjustment 175
6.5-3 Model Results 175
6.5-4 A 50 Percent Sugar Beet - 50 Percent Navy Bean Production Model 177

CHAPTER

6.5-5 Model Results 181
6.5-6 A 25 Percent Sugar Beet - 75 Percent Navy Bean Production Model 181
6.5-6 Model Results 183

7 SUMMARY AND CONCLUSIONS 186
7.1 Summary 186
7.2 Conclusions 191
7.2-1 Scope and Limitations 193
7.2-2 Future Research Needs 194

REFERENCES 195

APPENDIX A
Mixed Integer Linear Programming Models For Solving Navy Bean Production Systems in Michigan A-1

APPENDIX B
The Computer Results of the Mixed Integer Linear Programming Models B-1

APPENDIX C
Linear Programming Package by Harsh and Black (1975) C-1

APPENDIX D
Machinery Cost Computer Program by Rotz (1981) D-1

LIST OF TABLES

Table		Page
2-1	Tillage Systems for Navy Beans Production in Michigan	22
2-2	Rates and Type of Herbicide Used for Controlling Weed in Navy Bean Fields Planted in Wide Rows	26
2-3	Rates and Type of Herbicide Used for Controlling Weed in Navy Bean Fields Planted in Narrow Rows	27
2-4	Rates and Type of Herbicide Used for Controlling Weed in Corn Fields	28
2-5	Rates and Type of Herbicide Used for Controlling Weed in Sugar Beet Fields	29
2-6	Rates and Kinds of Fertilizers Used for Navy Bean, Corn, and Sugar Beet Production	30
3-1	Summary of Navy Bean Production Data	43
3-2	Summary of the Yields Conducted over a Three-Year Period for Swan Valley and Fleetwood	45
3-3	Summary of Corn Production Data	47
3-4	Summary of Sugar Beet Production Data	49
3-5	Kinds and Sizes of Implements Used in the Models	51
3-6	Purchase Price of Selected Implements (In Dollars Per Unit)	54
3-7	Purchase Price of the Implements Involved in Navy Bean, Corn, Sugar Beet Production	55
3-8	Summary of the Selected Implement Costs (For Ten Year Period)	58
3-9	Power Requirement for Implements in Medium-Textured Soil	61
3-10	Power Requirements for Selected Implements in Medium-Textured Soil and the Relevant Tractor Sizes	62
3-11	Machine Capacities (ha/hr) for Selected Implements	65
3-12	Predicted Portion of Days Suitable for Field Work in Saginaw at a 0.8 Level of Probability	72
3-13	Number of Hours Assigned to Field Operations	74
3-14	Calendar Days and Number of Available Hours for Field Work at 0.8 Probability Level for Bean Production	75

LIST OF TABLES (continued)

Table		Page
3-15	Calendar Days and Number of Available Hours for Field Work at 0.8 Probability Level for Corn Production	76
3-16	Calendar Days and Number of Available Hours for Field Work at 0.8 Probability Level for Sugar Beet Production	77
3-17	The Estimated Life of Machines	78
4-1	The Land Area that Can Be Covered by an Implement During Available Days and Time Required to Cover 200 Ha	91
4-2	Summary of the Adjusted Annual Cost of Tractors 1, 2, 3 Over Ten Year Period	96
4-3	Summary of the Final Solution of the Navy Bean Production System	97
4-4	Summary of the Shadow Prices and the Slacks for the Navy Bean Production Model	100
5-1	The Land Area that can be Covered by an Implement During the Available Workable Days and Time Required to Cover 200 Ha	116
5-2	Summary of the Final Solution of the Navy Bean-Corn Production Model	124
5-3	Summary of the Final Solution of the 75 Percent Navy Bean - 25 Percent Corn Production Model	134
5-4	Summary of the Final Solution of the 50 Percent Navy Bean - 50 Percent Corn Production Model	139
5-5	Summary of the Final Solution of the 25 Percent Navy Bean - 75 Percent Corn Production Model	141
6-1	The Land Area that can be Covered by an Implement During the Available Workable Days and Time Required to Cover 200 Ha	156
6-2	Summary of the Adjusted Annual Cost of Tractors 1, 2, 3 Over Ten Year Period	161
6-3	Summary of the Final Solution of the Navy Bean - Sugar Beet Production Model	163
6-4	Summary of the Shadow Prices and the Slacks Obtained from the Navy Bean-Sugar Beet Production Model	164
6-5	Summary of the Final Solution of the 25 Percent Navy Bean - 75 Percent Sugar Beet Production Model	176

LIST OF TABLES (continued)

Table		Page
6-6	Summary of the Final Solution of the 50 Percent Navy Bean - 50 Percent Sugar Beet Production Model	182
6-7	Summary of the Final Solution of the 75 Percent Navy Bean - 25 Percent Sugar Beet Production Model	184

LIST OF FIGURES

Figure		Page
2-1	Pulling operation of navy bean (conventional) harvesting method).	38
2-2	Windrowing operation of navy bean (conventional harvesting method).	39
2-3	Direct harvesting method of navy bean. . . .	40
3-1	Possible ways of matching tractor 1 (T_1) and selected implements.	67
3-2	Possible ways of matching tractor 2 (T_2) and selected implements.	68
3-3	Possible ways of matching tractor 3 (T_3) and selected implements.	69
3-5	Possible ways of matching tractor 4 (T_4) and selected implements.	70
5-1	Summary of the profits under different percentage of navy bean - corn.	142
6-1	Summary of the profits under different percentage of sugar beet - navy bean. . . .	186

LIST OF SYMBOLS

Crop Symbols

WD_1	Fleetwood planted in 35 cm and harvested. D
WD_2	Fleetwood planted in 70 cm and harvested. D
WC_3	Fleetwood planted in 70 cm and harvested. C
SD_1	Swan Valley planted in 35 cm and harvested. D
SD_2	Swan Valley planted in 70 cm and harvested. D
SC_3	Swan Valley planted in 70 cm and harvested. C
Co	Corn
Be	Navy beans
S	Sugar beets

Machine Symbols

T	Tractor
M	Moldboard plow
C	Chisel plow
Z	Fertilizer spreader
F	Field cultivator
R	Row planter
V	Row cultivator
S	Sprayer
B	Bean puller
W	Bean windrower
P	Beet topper
L	Beet lifter
H	Harvester

1. INTRODUCTION

1.1 Basis of the Problem

For many years, dry edible beans have played a significant role in people's diets, especially in developing countries. Where the price of meat is relatively high and people eat primarily food from cereal, grain legumes, and root crops. Navy beans have occupied an important part of Michigan's agriculture. During 1950-54 Michigan produced 22 percent of the U.S. dry beans. This rose to over 40 percent between 1960-64, but has been declining, and was 28 percent in 1976. It is, therefore, important to maximize the crop productivity and minimize the production costs in order to satisfy the increased demand at an acceptable price level.

There are currently two navy been production systems in use in Michigan. One is the conventional method which involves planting the navy beans in wide rows (70 cm) and makes use of a blade puller, windrower, and a combine with a pickup header to accomplish the harvesting operation. The second system is the direct harvesting method which allows for planting the navy beans in either wide rows (70 cm) or narrow rows (less than 50 cm), and makes use of only a combine with a pickup reel and a flexible floating cutterbar to carry out the harvesting operation.

The direct harvesting method offers several potential benefits to bean producers. With direct cutting, the number of field operations would be reduced by the elimination of pulling and windrowing. In addition, risk of weather damage would be decreased since all unharvested beans would be left standing rather than on the ground as they are after pulling or windrowing. Furthermore, the harvested beans would probably be of better quality because of the reduced amount of soil and stones in the beans. The direct harvesting method has slowly increased in popularity among farmers. This can be attributed mainly to the excessive losses caused by applying the direct harvesting methods to the old navy bean varieties. With the development of the high yielding upright navy bean variety (Swan Valley), it was believed that its productivity could be further improved by using a different production management system (Kelly et al, 1981).

With these considerations in mind, navy bean producers are thus concerned with which navy bean variety to produce, Swan Valley (upright) and Fleetwood (standard) planting system to follow (wide rows or narrow rows) and harvesting method to use (conventional or direct). In addition, because of the fluctuation of the crop's market prices, navy bean producers are also concerned about alternate crop that can be planted with navy beans to reduce the market risk using the same machinery set available for navy bean production, with respect to crop rotation systems.

1.2 Literature Review

1.2-1 Harvesting Practice—Developments

During the period from 1947 to 1958 practically every known method of bean harvesting operation had been tried in Michigan. The various harvesting methods may be classified as follows:

1. Pulling by a blade type cutter usually in the form of a cultivator attachment
2. Cutting with rotary crop cutter
3. Windrowing with a bean windrower or with a side delivery rake
4. Bunching by moving segments of windrows into bunches or by using a buncher attachment on a puller
5. Stacking either by hand or machine
6. Hauling to a thresher or to barn storage for winter threshing
7. Stationary threshing
8. Threshing machine converted to a combined harvester-thresher by the addition of a chassis and pneumatic tires, auxiliary motor and special pickup feeder
9. Use of a special bean combine
10. Small grain combine fitted with "bean attachment" equipment

McColly (1958) reported on research conducted in Michigan which indicated that a blade-type bean harvesting method tends to push dirt and stones into the windrow with the beans. In direct combining tests, a combine with a finger-type reel was more efficient than the standard bat-type reel because the tines could be adjusted to incline slightly upward as they lifted the bean plant toward the cutterbar. This action saved many bean pods from being severed by the sickle and decreases cutterbar and shatter losses by 50 percent. The report also indicated that in direct cutting of beans the rigid cutterbar ran in the soil part of the time in order not to cut an excessive number of low-hanging pods.

Gunkle and Anstee (1962) reported that the performance of the direct-harvester, rubber-fingered belt attachment on red kidney and white narrow beans was satisfactory. Average losses with this rubber-fingered device on red kidney beans ran 2.62 bushel per acre. Some difficulty was encountered in using this unit on very low-growing beans. Under these conditions there were considerable scatter losses and plugging in the throat area. A special belt puller attachment was also designed, constructed, and field tested for the self-propelled combine. The initial results indicated that losses were over double those resulting from conventional harvesting. But after the attachment was modified the losses reduced to an average 2.87 bushel per acre. The double-belt puller was also tested and results indicated that when operating in optimal conditions at a speed of 1 to 2 miles per hour, the losses were slightly less than 1 bushel per acre.

Pickett (1971) conducted an experiment for evaluating the performance of a floating cutterbar and pickup reel for direct harvesting of edible beans. The report indicated that a floating cutterbar followed the ground surface well if the header height was properly set. The pickup reel did not effectively convey the bean plants across the cutterbar because of the short plant height and neither the reel fingers nor the reel bats were close enough to each other to effectively handle bean plants. Also header losses may be reduced by modifying the reel or developing another means of conveying.

Pickett (1972) conducted another experiment for evaluating the row direct-cut header. The individual row unit header consisted of the basic grain header plus four modified bean buckets each having a reel. The results indicated that the row unit header cut the beans within 2 inches of the ground with little loss when the header was centered on ridged bean rows and the beans were standing well. Increasing the reel index caused the plant to be hit while being cut resulting in increased shattering losses.

Visual observations of the headers during operation and samples of losses collected indicated that a higher percentage of the loss from the row unit header was due to beans still in pods rather than for the floating bar header. Many of the pods lost by the row unit header were still attached to the plant but some were attached and laying on the ground.

Frushour and Johnson (1974) developed a new pull-type combine suitable for harvesting either peanuts or edible dry beans or both. This new machine reportedly offered these advantages:

1. A capacity equal to or greater than that of the self-propelled combine, especially in weedy or green conditions
2. A quality of beans from this new design consistently better than that from modified small grain combine
3. Much lower cost than a self-propelled combine of equivalent capacity.

Quick and Buchele (1974) conducted an experiment on soy beans to study the effect of using a combine with a flexible cutter bar on the header losses. The report indicated that total header losses were reduced by 39.9 percent compared to a combine with a standard cutterbar. Also they listed the advantages of using the floating cutterbar attachment as follows:

1. A highly significant reduction in header losses
2. The ability to cut uniformly lower by accommodating to ground irregularities
3. Higher forward speed for the same header loss level
4. Some degree of rock protection for header
5. Smoother crop feeding under the platform auger.

According to Pickett (1975), in two years of tests using the conventional harvesting method in Michigan, gathering loss was approximately 10 percent when operating at 2.5 to 3 miles per hour in standing beans. With the direct harvest method using a combine with a floating cutterbar under typical field conditions, the header loss may be 15-25 percent.

Kelly et al (1982) reported that four upright black and navy bean varieties (Swan Valley, Fleetwood, Domino, and T-39) were tested in two counties in Michigan during the 1981 harvest season. The results in Saginaw county indicated that the header losses via the direct harvest method ranged from 17.3 percent (in T-39) to 41.3 percent (in Fleetwood), while gathering losses ranged from 7.7 percent (in Fleetwood) to 16 percent (in Domino) via the conventioal harvesting method. In Gratiot county, the header losses were reported in the range of 6.7 percent (in Swan Valley) to 11.4 (in Fleetwood) using the direct harvesting method, while the gathering losses in the conventional method ranged from 1.9 percent (in Swan Valley) to 8.3 percent in (Domino).

Considering the effect of pod and grain moisture content on threshing loss and damage of navy beans, McDow (1949) reported a splitting effect on navy beans that may have been caused by poor machine adjustment and/or low grain moisture content. According to King and Riddles (1962), damage to beans (and to other crops) could be reduced by avoiding high cylinder speed even at fairly low-moisture content. Hoki and Pickett (1973) reported the damage to the seed coats only increased from 5 percent at an impact velocity of 10.5 $m.sec^{-1}$ to over 60 percent at a velocity of 17.78 $m.sec^{-1}$. Narayan (1969) reported optimum moisture content for minimum "checking" of navy bean seed coats in the range of 13.4 to 15.6, and it is usually stated that beans should be harvested when grain mositure content is in the range of 15 to 20 percent.

Pickett (1973) reported that an increase in cylinder speed resulted in decreased threshing loss and an increased damage for each level of bean moisture content. Also the report indicated that excellent conditions for harvest include navy bean moisture between 17 and 20 percent and pod moisture as low as possible, preferably below 12 percent.

Singh and Linvill (1977) developed a model for the rate of change of navy bean pod moisture content as related to temperature change. Their analysis indicated that the coefficients of the difference between pod and grain moisture terms were not statistically different, but pod moisture and temperature change coefficients were significantly different.

The results obtained regarding the direct harvesting method of navy beans indicated that some difficulty was encountered in using the rubber-fingered belt attachment on very low-growing beans. However, the double-belt puller gave better results (Gunkle et al, 1962). The use of a combine with a finger-type feed was found to be more efficient than the standard type (McColly, 1958). However, neither the reel fingers nor the reel bats were close enough together to effectively handle bean plants (Pickett, 1971).

When considering cutterbar performance, the standard cutterbar was found to run in the soil part of the time in order not to cut an excessive number of low-hanging pods (McColly, 1958). However, the flexible floating cutterbar was found to follow the ground surface well if the header height was properly set and to reduce header losses compared to the standard cutterbar (Pickett, 1971, 1972).

The results about the reel index indicated that increasing the reel index caused the plants to be hit while being cut resulting in increased shattering losses (Pickett, 1973). Increasing the cylinder speed resulted in decreased threshing loss and increased damage for each level of moisture content. Also excellent conditions for harvest were reported as bean moisture of 17-20 percent and pod moisture as low as possible (Pickett, 1973).

With the development of the new high yielding upright navy bean variety (Swan Valley), that header losses were less in Swan Valley compared to Fleetwood (standard navy).

These header losses were classified under four categories:

1. Shatter losses: loose or free beans and beans in pod detached from the plant.
2. Stalk losses: beans in pods attached to stalk pieces which were cut but not collected.
3. Stubble losses: beans in pods attached to the free standing stubble left by the machine.
4. Lodge losses: beans in pods attached to stalks or branches abnormally longer than the stubble which slipped under the cutter bar (Kelly et al, 1982).

1.2-2 Machinery Selection Model Approaches

Machinery selection is an important part of machinery management. The complexity and the magnitude of the machinery selection problem in the analysis of crop production systems has led to numerous efforts to develop analytical models as a decision aid. Link (1967) suggests an "activity net work" technique to estimate net returns and machine optimum size. In this approach, some factors were ignored. The most important of these were system effects and weather risk. All the machines on a farm are interrelated through a set of operating procedures and practices. Machines used for different crops may influence on each other as, for example, hay-harvesting and corn-cultivation machinery.

Hughes (1974) developed a simulation model for selection of field machinery system and estimation of system cost. Some problems were encountered in terms of energy requirements, time required for field work, and estimating the life of field machines.

Danok et al. (1978) developed an optimization model to solve simultaneously for machinery selection, crop production, and labor hiring for a state farm in Iraq. The cropping possibilities considered in the model were wheat, flax, clover, safflower, cotton, and corn. The production of each crop involved plowing, disking, planting, irrigation, and harvesting operations.

Singh and Holtman (1979) developed a heuristic algorithm to evaluate and compare selected crop production systems over a range of farm sizes with respect to costs and requirements for machinery, labor, and fossil fuels for field work. The crop production systems considered involved corn, soybeans, field beans, wheat, and alfalfa using no till, chisel plow, or moldboard plow tillage practice.

Krutz et al (1980) used a linear programming model (i.e., the Purdue model B-93 and the International Harvester pro-Ag program) to evaluate alternative farming situations in order to provide general guidelines of machinery selection for corn/soybeans crop production. The report indicated that linear programming models can be extremely useful tools to individual farm managers for evaluating machinery-sizing decisions for a particular situation. They can also be useful for conducting quasi-research studies to determine equipment size, capacity, and profit relationships of a more general nature.

Danok et al. (1980) used a mixed integer programming technique for solving the problems of crop and machinery choice. The model maximizes profit, which is cropping profit less machinery cost, subject to the following:

1. Constraints on resources which link machinery and cropping activities
2. Constraints that reflect mutual exclusivity of machinery
3. Constraints which link machine set purchase and use
4. Constraints on other cropping resources

Whitson (1981) used a linear programming model to maximize returns to the fixed resources of a farm given the limitation of land, hours of available field time (weather risk), machinery characteristics (size, kind, etc.).

Linear programming models have been applied as a useful tool to maximize net profit or to minimize total cost with respect to available resources. The linear programming technique was used to select the best crop mix with consideration of the machinery complement. An example is the Purdue model by Krutz 1980. Mixed integer linear programming models were applied where several alternate machinery components were stored in data blocks, and the model searched for the best set to match the best crop mix (an example is Danok's model 1978). Heuristic models assumed that field operations must be completed within specific calendar periods so that profit can be maximized. The objectives of these models were to compare and select crop production systems over a range of farm sizes with respect to labor, machinery requirements, and fuel (an example is the Singh model 1979 and Wolak, 1981).

It is obvious from the previous research work that MILP model has been used successfully to evaluate machinery-sizing decisions for a particular situation. Therefore, it was adopted to solve navy bean, navy bean-corn and navy bean-sugar beet production system in Michigan with respect to the following constraints:

1. Land size,
2. Available machinery,
3. Available time,
4. Power requirements,

so that profit can be maximized.

1.3 Objectives

The overall objective of this study was to evaluate and compare two navy bean varieties in Michigan, Swan Valley (upright) and Fleetwood (standard navy), applying different management systems to maximize the net profit. In order to meet the overall objective, the specific objectives were as follows:

1. To develop an MILP model which utilizes parameters collected in the field and from pertinent literature to select
   a. The navy bean variety to be recommended (Swan Valley or Fleetwood)
   b. The type of planting system to follow (wide rows or narrow rows)
   c. The kind of harvesting method to apply (conventional or direct)
   d. The machinery set to use in the selected navy bean production system
2. To determine the net profit obtained from the selected navy bean production system and analyze the sensitivity of the optimal solution.

This study also considered the impact of having two mixed crop production systems (navy bean-corn, and navy bean-sugar beet) on the farmer's profit in Michigan. The specific objectives were as follows:

3. To develop an MILP model in order to
   a. Select the most economical crop to be produced in each production system
   b. Estimate the net profit that could be made under different percentages of a mixed crop system
   c. Select the types and sizes of farm machinery to contribute to each production system.

4. To analyze the sensitivity of the optimal solution in the navy bean-corn and navy bean-sugar beet production systems.

2. METHODOLOGY

2.1 A Mixed Integer Linear Programming Approach (MILP)

General linear programming* involved selection of a set of decision variables and their quantities that maximize a linear objective function subject to a series of linear restrictions and the requirement that the decision variable cannot be negative. In other words, linear programming models deal with the problems of allocating limited resources among competing activities in the best possible (i.e., optimal) way. The standard LP matrix model can be presented as follows:

Resource / Activity	Resource usage 1	2	n	Amount of resource available
1	a_{11}	a_{12}	a_{1n}	b_1
2	a_{21}	a_{22}	a_{2n}	b_2
3				
m	a_{m1}	a_{m2}	a_{mn}	b_m
Z/Unit	C_1	C_2	C_n	
Level	X_1	X_2	X_n	

*Frederick S. Hillier and Gerald J. Lierman, Introduction to operations research, Stanford University, 1980.

where X_j = Level of activity j for j = 1, 2, . . . n

Z = Overall measure of effectiveness

C_j = The increase in Z that would result from each unit increase in X_j for j = 1, 2 . . . n)

b_i = The amount of resource i available for allocation (for i = 1, 2 . . . n)

a_{ij}= Amount of resource i consumed by $_j$th unit of activity

The mixed integer linear programming mode can be used where some of the variables (say, 1 machine type in this model) are restricted to integer values but the rest are ordinary, continuous variables. In this case, this model can be presented in algebraic terms as follows:

$$\text{Max } Z = \sum_{j=1}^{n} C_j X_j$$

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \quad \text{for } i = 1, 2 \ldots m)$$

and

$$X_j \text{ integer} \quad \text{for } j = 1, 2 \ldots I \ (I<n)$$

$$X_j \geq o \quad \text{for } j = 1, 2 \ldots n$$

A linear programming package designed by Hansh and Black (1975) was used to solve the MILP models. This package can handle modest- sized of linear programming when the objective is maximized subject to series of constraints.

2.2 Model Assumptions

2.2-1 Tillage system

Tillage practices continue to play an important role in the seedbed preparation process. Traditionally, farmers have practiced tillage operations in terms of standard treatments for all fields regardless of the kind of soil, amount of crop residues, or species and amounts of weeds. Generally, there are two major tillages in use in Michigan: primary tillage and secondary tillage.

Primary tillage involves complete treatment of the surface soil to reduce soil strength, destroy weeds, cover plant material, and arrange aggregates. The moldboard plow is the best suited to the more level fields, especially those containing fine-textured soil. The chisel plow is increasing in popularity in several parts of the state. This implement is superior to the moldboard plow on sandy soil and where there is a slope, because it leaves some crop residue on the surface of the soil. Other advantages of using the chisel plow are as follows:

1. Decreasing both wind and water erosion
2. Lower power requirements per unit width
3. Greater tillage width

Secondary tillage operations are intended to create refined soil conditions following primary tillage. Disk harrows and field cultivators are common secondary tillage tools used in early spring for leveling the soil surface.

Many factors affect the choice of a tillage system and the type of tillage implements. In general most farmers practice primary tillage in fall using either a moldboard or chisel plow. Other farmers practice the primary tillage operation in spring because of inappropriate weather conditions during fall. Secondary tillage in spring is done with disk harrows or field cultivators. In this study spring-primary tillage operation and fall-secondary tillage were assumed to be involved in navy beans, navy bean-corn, and navy bean-sugar beet production systems. Table 2-1 represents the major tillage systems applied for beans in Michigan.

In the navy bean production model, moldboard and chisel plows were assumed to be included in primary tillage implements, and field cultivators as secondary tillage implements.

In the navy bean-corn, and navy bean-sugar beet models, moldboard or chisel plows were assumed to be included as primary tillage implements depending upon the type of tillage implement that would be chosen in the navy bean production model. The reason for this assumption is to make use of the same tillage tool for the navy bean, navy bean-corn, and navy bean-sugar beet production systems.

TABLE 2-1
TIllage Systems for Navy Beans
Production in Michigan

System No.	Tillage Code	Time of Tillage	
		Fall	Spring
	A	. . . .	No-till
1	B	. . . .	Primary-plant
	C	. . . .	Primary-secondary-plant
	A	Subsoil	No-till
2	B	Subsoil	Primary-plant
	C	Subsoil	Primary-secondary-plant
	A	Primary	Plant
3	B	Primary	Secondary-plant
	C	Primary-secondary	Plant
	D	Primary-secondary	Secondary-plant
	A	Subsoil-primary	Plant
4	B	Subsoil-primary	Secondary-plant
	C	Subsoil-primary-secondary	Plant
	D	Subsoil-primary-secondary	Secondary-plant

SOURCE: L.S. Robertson and R.D. Fraser, eds. Dry Bean Production: Principles and Practices. Extension Bulletin 1251, Cooperative Extension Service and Agricultural Experiment Station, Michigan State University, East Lansing, August 1978.

2.2-2 Weed Control

The effect of weed competition on the growth of row crops has been a serious problem in many areas. Yield is usually reduced as a result of weeds sharing nutrients, light, space, and water with row crops. In some crops, weed growth may increase harvest losses and may also cause problems when dry weedy material goes through the combine into the grain. Therefore, weeds must be controlled to increase yields, and maximize economic returns by selecting an appropriate weed control program that can fit the area and the crop conditions.

Two weed control practices have been used to overcome the weed competition. First is mechanical cultivation which involves controlling weeds between rows after seeds are planted or after plants have emerged. Second is the use of herbicide which can contribute successfully if it is applied beside the cultivation. In this case, weeds between rows can be controlled mechanically while weeds beside plants can be controlled chemically.

Currently, there are three methods for applying herbicides. The first is the "preplant incorporated" method (PPI). In this method the herbicide is incorporated in the upper 5 to 7.5 cm of the top soil layer by using some form of a harrow before planting.

The second is the "preemergence" method. In this method the herbicide is applied to soil surface when the crop is planted. The herbicide finds its way, with the help of timely rains to the zone of weed seed germination (5 to 7.5 cm below the soil surface).

The third method is the "postemergence" application. In this case, herbicide is applied after the crop has emerged from the soil.

In this navy bean production model, beans planted in wide rows were assumed to be treated chemically and mechanically to control weeds. Preplant herbicides were assumed to be placed by harrows in the weed seed germination zone to control weeds chemically, while tractor-mounted cultivators were considered to be used for controlling weeds mechanically.

In the narrow row system, beans were assumed to be treated only chemically by the use of preplant and preemergence herbicide applications.

It has been found that effective weed control in corn production involves the use of herbicides beside mechanical cultivation (Extension bulletin E-1429). Therefore, in the navy bean-corn model, the existing weeds in the corn field, were assumed to be treated by preemergence herbicide applications and row cultivators, although some farmers prefer to use only the chemical application to control the weed in the corn fields.

Weed control in sugar beet fields is important because weeds harbor insects and serve as alternative hosts for many diseases and cyst nematodes. There are several options open to the sugar beet grower for weed control. In the navy bean-sugar beet model, weeds in sugar beet fields were assumed to be treated by postemergence herbicide applciation, and by the use of row cultivators.

Tables 2-2, 2-3, 2-4 and 2-5 represent the rates and the type of herbicides used for controlling weeds in navy beans planted in wide and narrow rows, corn, and sugar beet fields, respectively.

2.2-3 Fertilizer Applications

The amount of fertilizer needed for a crop is closely related to the nutrients already in the soil. The best way to determine the amount of nutrients available in the soil is with a soil test. The values obtained from the soil tests are correlated with the response by plants to applied nutrients (Extension bulletin E-550).

Although, different farms need different kinds and rates of fertilizer, application number 1 in Table 2-6 was used as a standard practice in the navy bean production model. In the wide row system (70 cm row spacing) the fertilizer was assumed to be placed 5 cm to the side of seed rows and 5 cm below the seeds during the planting

TABLE 2-2

Rates and Type of Herbicide used for Controlling Weeds in Navy Bean Fields Planted in Wide Rows

Weed Controlled	Time	Herbicide Name	Kg/ha
Annual broad leaf		EPTC (Eptam)	2.5
		+	
(Including night shade	Preplant	Chloramben (Amiben)	2.24
		+	
and		Trifluralin (Treflan)	0.56
Annual grass)		OR	
		Profluralin (Tolban)	0.84

SOURCE: Michael Barrett and William Meggitt, Weed Control for Field Crops. Extension Bulletin E-434, Cooperative Extension Service, Michigan State University, East Lansing, 1982.

*Eptam and Amiben can be mixed with either Treflan or Tolban.

TABLE 2-3

Rates and Type of Herbicide Used for Controlling Weeds in Navy Bean Fields Planted in Narrow Rows

Weed Controlled	Time	Herbicide Name	Kg/ha
Annual broad leaf		EPTC (Eptam)	2.5
		+	
(Including night shade)	Preplant	Trifluralin (Treflan)	0.56
		+	
and		Profluralin (Tolban)	0.84
Annual grass			
	Followed	Chloramben (Amiben)	2.24
	by	OR	
		Dinoseb (Premerge)	5.0
	Pre-emergence	OR	
		Chloramben (Amiben)	1.12
		+	
		Dinoseb (Premerge)	3.36

SOURCE: Michael Barrett and William Meggitt, Weed Control for Field Crops. Extension Bulletin E-434, Cooperative Extension Service, Michigan State University, East Lansing, 1982.

TABLE 2-4

Rates and Type of Herbicide Used for Controlling Weed in Corn Fields

Weed Controlled	Time	Herbicide Name	Kg/ha
Annual broad leaves, annual grasses (including panicum green foxtail, giant foxtail witchgrass and crabgrass)	Pre-emergence	Atrazine	1.13
		+	
		Lasso	2.26

SOURCE: Michael Barrett and William Meggitt, Weed Control for Field Crops. Extension Bulletin E-434, Cooperative Extension Service, Michigan State University, East Lansing, 1982.

TABLE 2-5

Rates and Type of Herbicide Used for Controlling Weed in Sugar Beet Fields

Weed Controlled	Time	Herbicide Name	Kg/ha
Annual broad leaves		Desmedipham (Betanex)	0.56
	Post-emergence	+	
(Including smart-weed)		Phenmedipham (Betanal)	0.56
		+	
		Endothall (H 273)	0.56

SOURCE: Michael Barrett and William Meggitt, Weed Control for Field Crops. Extension Bulletin E-434, Cooperative Extension Service, Michigan State University, East Lansing, 1982.

TABLE 2-6

Rates and Kinds of Fertilizers used for Navy Beans, Corn, and Sugar Beet Production

Appl. No.	Crop	Fertilizer Name	Rate (Kg/ha)
1*	Navy beans	N	56
		P_2O_5	84
		K_2O	112
		Zn	3.36
		Mn	9
2**	Corn	N	150
		P_2O_5	70
		K_2O	90
3***	Sugar beets	N	80
		P_2O_5	75
		K_2O	150

*SOURCE: Crop and Soil Science Department, Michigan State University, East Lansing, Michigan.

**SOURCE: Farm Management, Department of Ag. Economics, Missouri.

***SOURCE: D.D. Warncke and D.R. Christensen, Fertilizer Recommendations: Vegetable and Field Crops in Michigan. Extension Bulletin E-550. Cooperative Extension Service, Michigan State University, East Lansing, Michigan, December 1981.

operation, while it was assumed to be broadcast prior to planting time in the narrow row system (35 cm) using the fertilizer spreader. These assumptions were made because these practices were adopted during the experimental stages in 1980, 1981, and 1982.

Fertilizer recommendations ($N+P_2O + K_2O$) for corn production fluctuated from place to place depending upon the soil test and the yield goal. In Table 2-6 aplication 2 represents the amount of fertilizer considered in the navy bean-corn model for corn production. This fertilizer was considered to be banded by planters at planting time (Extension bulletin E-1429)

In considering sugar beet production in Table 2-6, application 3 was adopted to the navy bean-sugar beet model for sugar beet production. This fertilizer was also assumed to be applied by planters at planting time (Extension bulletin E-1524).

2.2-4 Planting Systems

Optimum plant population is essential for high yields. A very high population or seeding rate can result in excessive plant competition for water and nutrients. Below-optimum seeding rates can result in incomplete use of water, nutrients, and light.

For many years, 70 cm (28 inch) row spacing has been practiced for planting navy beans in Michigan because farmers can take advantage of the same machinery set for planting, spraying, and cultivating some other similar crops such as corn, soybeans, and sugar beets. At this row width and 5 cm spacing in the row, 45 kg of seeds are required, giving density of about 250,000 plants per hectare (100,000 plants per acre) if all seeds germinated. Beans are normally planted between 5 to 7.5 cm deep in moist soil depending upon the type of soil (Extension bulletin E-1251).

Most farmers use the conventional harvesting method (using a puller, windrower, and a combine with a pickup header to harvest the 70 cm row spacing beans.

Recently, some new varieties have been developed which can stand up better compared to the conventional varieties. Therefore, there is a tendency toward planting beans in narrow rows (50 cm or less) and applying the direct harvesting method (using only a combine with a floating cutterbar and a pickup reel) to harvest the crop. At 35 cm (14 inches) row width about 67 kg of navy bean seeds are required per hectare, giving densities of about 375,000 plants per hectare (150,000 plants per acre).

In this particular study, two navy bean varieties (Swan-Valley and Fleetwood) were considered in the model to be planted in two-row spacing systems (70 cm and 35 cm) in order to compare and select the more appropriate row spacing system to practice.

Plant population has a significant effect on corn yield. Although the optimum population will vary with yield level, test results show 45,000 to 50,000 plants per hectare at harvest to be an optimum population over a rather wide yield range (Extension bulletin E-1429).

Row width is another production practice which affects corn yield. Planting corn at 70 cm row spacing width with a 14 kg seeding rate per hectare has given good results in the experiments conducted in East Lansing experiment station. It is recommended that corn seeds be planted 1.5 to 3 cm deep in cool soil, and between 3 to 6 cm deep during late planting when the soil surface is more likely to become dry (Extension bulletin E-1429).

Commercial sugar beet growers plant sugar beets at 15 to 20 cm spacing between seeds in the row. When growing beets for the first time, it is recommended that a 5 to 7.5 cm spacing be used. Generally, row width is governed by spacing used in other crops. In the sugar beet-navy bean model, sugar beet seeds were assumed to be planted at a 70 cm spacing in 70 cm rows at a seeding rate of 1.13 kg per hectare (Extension bulletin E-1524).

2.2-5 System of Cropping

Cropping systems refers to the detailed organization, method of operation and practices used in producing a series of crops. A good cropping system would reduce soil erosion to a practical minium, reduce the risk of an explosion in an insect disease and weed population and improve a crop productivity.

In this particular study, the effect of cropping system on navy bean, corn, and sugar beet was not taken into consideration assuming that the farmer would follow a cropping system as to maintain a good yield level. The MILP models in this case reflect the cropping system in one year as to compare among different crop production possibilities and select the most appropriate production system.

2.2-6 Insect and Disease Control

It has been noticed that the incidence and the severity of a particular disease vary from year to year, due to environmental and management practices. Several species of pests may also appear in large number during some years causing damage to field crops. Therefore, farmers have practiced different methods of disease and pest control programs in order to protect the yield and the quality of crops before the damage is done. The use of a combination of methods which cause as little environmental damage as possible in the process is the basis of all pest and disease control programs (Extension bulletin E-1251).

Chemical application by sprayers is a common field operation in crop production. The PTO-driven trailed sprayers were considered to be involved in the navy beans, navy bean-corn, and navy bean-sugar beet production systems for applying chemicals during the insect and disease control programs.

2.2-7 Harvesting Methods

Two navy bean harvesting methods have been practiced in Michigan. One is the conventional method which makes use of pullers, windrowers, and combines. With the conventional harvesting method, beans are pulled by pullers when seed moisture content drops to approximately 20 percent. Then these plants are windrowed with either center delivery or side delivery windrowers. Collecting and threshing operations are carried out using combines with pickup attachments.

The second method is that of direct harvesting which makes use of combines with pickup reels and flexible floating cutterbars to combine and thresh beans. Figures 2-1 and 2-2 represent the conventional harvest method (pulling and windrowing operations), while Figure 2-3 shows the direct harvesting method.

Both navy bean harvesting methods were tested during 1980, 1981 and 1982 harvesting seasons with two varieties (Swan Valley and Fleetwood). The results of these experiments were used in the navy bean model to study the impact of different navy bean production systems on the farmers' profits.

It has been found in the direct harvesting method that the performance of a combine equipped with a flexible floating cutterbar is better than a rigid cutterbar. Therefore, two different sizes of self-propelled combines equipped with different heads (pickup heads for harvesting beans conventionally and pickup reels with flexible floating cutterbar for harvesting beans directly) were assumed to be involved in harvesting beans while the same combines equipped with 4 or 6 rows were assumed to be used in harvesting corn. The sizes of the combines were chosen to suit the land size of 200 ha which was assumed in the MILP model.

There are several alternatives for harvesting sugar beets in Michigan, the most common method is to use beet toppers and beet lifters. Therefore, both types of implements were considered in the navy beans-sugar beet model to contribute in harvesting beets.

Fig. 2-1. Pulling operation of navy bean (conventional harvesting method).

Fig. 2-2. Windrowing operation of navy bean (conventional harvesting method).

Fig. 2-3. Direct harvesting method of navy bean.

3. DATA COLLECTION

3.1 Navy Bean Production

There are currently two navy bean planting systems in use in Michigan; wide rows and narrow rows. In wide rows, beans are usually planted in 70 cm row spacing and harvested conventionally using a puller, windrower, and a combine with a pickup header attachment, or harvested directly using a combine with a flexible floating cutterbar and finger-type reel. Beans planted in narrow rows (35 cm) are usually harvested directly.

The data collected during the investigation about the two navy bean planting systems included the following:

1. Although the rates and the kinds of fertilizers fluctuate according to the type of soil, the rates of fertilizers were assumed to be the same for both planting systems (wide rows and narrow rows).
2. Interviews with farmers and county extension agents revealed that farmers were using almost the same kinds and application rates of insecticides and fungicides for both planting systems.
3. According to the information collected from the Michigan State University Crop and Soil Science Department, the seeding rate for both navy bean varieties (Swan Valley and Fleetwood) are the same

under the same row spacing width.

Table 3-1 represents the navy bean production data collected during the investigation.

With the development of the high-yielding, upright (Swan Valley) variety it was believed that its productivity could be further improved by using a different production-management system (Kelly et al, 1982). Therefore, several experiments were conducted in Saginaw and Gratiot Counties during the 1980-81 and 82 harvest seasons to estimate the yields and header losses for Swan Valley and Fleetwood applying different production systems.

In 1980 and 81 experiments, Swan Valley and Fleetwood were planted in 70 cm rows and harvested conventionally and in 35 cm rows were harvested directly (Kelly et al, 1980, 1982). The yields and losses collected for both navy bean varieties were collected and averaged. In the 1982 experiments, Swan Valley was planted in 70 cm row spacing and directly harvested. The yield and the header losses were recorded.

Because of insufficient data about the header losses for Fleetwood planted in 70 cm and directly harvested, some samples were taken from Fleetwood planted in 50 cm and directly harvested to estimate the yield and the header losses. The percentage of header losses in 50 cm rows was taken as a base for estimating the approximate header losses in 70 cm row spacing.

TABLE 3-1

Summary of Navy Bean Production Data

Requirements	Unit	Swan Valley		Fleetwood	
		70 cm rows	35 cm rows	70 cm rows	35 cm rows
Seeding rate	kg/ha	45.0	67.0	45.0	67.0
Fertilizer rate	kg/ha	270.0	270.0	270.0	270.0
Herbicide rate	kg/ha	5.3	10.6	5.3	10.6
Seed price	$/kg	0.88	0.88	0.88	0.88
Fertilizer price	$/kg	0.47	0.47	0.47	0.47
Herbicide price	$/kg	14.15	14.15	14.15	14.15
Pesticide	$/kg	40.0	40.0	40.0	40.0
*Navy bean price	$/kg	0.44	0.44	0.44	0.44

SOURCE: Dr. Jim Kelly, Crop and Soil Science Department, Michigan State University.

Personal communication with extension agents and some local dealers.

Michigan Statistical Abstract 1981. 16 ed. Detroit: Bureau of Business Research, Wayne State University, April 1982

Other sources of losses (threshing, straw walker, shoe and leakage) were considered to be 4 percent from the total yield for both varieties under both harvesting methods.

The summary of the results are presented in Table 3-2. It is obvious from the results that Swan Valley variety planted in 70 cm and directly harvested gave the best yield. This result can be attributed to the crop-lodging problem in the narrow-row system during harvesting time which caused excessive losses. In the conventional method, the estimation of beans lost during pulling and windrowing were inaccurate because some beans were buried during pulling and windrowing. In the direct harvest method, the header losses were counted under four categories; shatter losses, stalk losses, stubble slooses and lodge losses.

3.2 Corn Production

Corn acreage and yield per hectare have both increased substantially in Michigan over the past 15 years. Corn may be grown in a wide range of soils from sands to clays to muck. However, without irrigation, highest yields are obtained on the finer-textured soils.

Date of planting trials at Michigan State University have consistently shown a yield advantage for corn planted in late April or early May over that planted later in May or early June (Extension bulletin E-1429).

TABLE 3-2

Summary of the Yields Conducted over a Three-Year Period for Swan Valley and Fleetwood

Variety	Unit	Direct Harvest		Conv. Harvest
		70 cm rows	35 cm rows	70 cm rows
Swan Valley	kg/ha	2605	1808	1903
Fleetwood	kg/ha	1660	1130	1788

SOURCES: Dr. Jim Kelly, Crop and Soil Science Department, Michigan State University and personal data collection during the 1981 and 1982 harvest season.

Data collected during the investigation about corn production indicated the following:

1. Fertilizer recommendations ($N + P_2O_5 + K_2O$) for corn are made by a soil test laboratory taking into consideration not only the soil test level but also the yield goal and the kind of soil tested. In this particular study, applying 150 kg of nitrogen (N), 70 kg phosphate (P_2O_5), and 90 kg of potash (K_2O) per hectare were assumed in the model. (See Table 2-6)
2. The average corn yield per hectare was estimated over a ten year period (72-81) from the Michigan Statistical Abstract (1981).
3. The average corn price in the market was also estimated over ten years period from the Michigan Statistical Abstract (1981).

A summary of the corn production data is shown in Table 3-3.

3.3 Sugar Beet Production

Sugar beets are usually grown in Michigan for sugar production under contract with a sugar company. Beets can be grown on mineral soils ranging from loamy sands to clays and on organic soils.

TABLE 3-3

Summary of Corn Production Data

Requirements	Unit	Value
Seeding rate	kg/ha	14.0
Herbicide rate	kg/ha	3.4
Fertilizer rate	kg/ha	310.0
Seed price	$/kg	0.18
Fertilizer price	$/kg	0.33
Herbicide price	$/kg	15.0
Insecticide + Fungicide	$/kg	40.0
Corn yield	bu/ha	238.00
Corn price	$/bu	2.37

SOURCES: Michigan Statistical Abstract 1981. 16 ed. Detroit Bureau of Business Research, Wayne State University, April 1982, and pesonal communication with extension agents, and some local dealers.

Sugar beets should be planced as early as possible. In the southern half of lower Michigan, April 15 to 20 is a good starting period. Further north this date will usually have to be delayed somewhat (Extension bulletin E-1524).

Data collected during the investigation about sugar beet production indicated the following:

1. Seeding rate per hectare may be varied from place to place depending on seed size, row width and space in rows.
2. The amount of fertilizer needed is best determined by a soil test, but for this particular study, applying 90 kg of nitrogen (N), 85 kg of phosphate (P_2O_5), and 170 kg of potash (K_2O) per hectare were taken into consideration (see Table 2-6).
3. The average beet yield per hectare was estimated over a five-year period (77-81) from the Michigan Statistical Abstract (1981).

The average price of sugar beets was also estimated over a five-year period (77-81) from the Michigan Statistical Abstract (1981).

The summary of sugar beet production data are show in Table 3-4.

TABLE 3-4

Summary of Sugar Beet Production Data

Requirements	Unit	Value
Seeding rate	kg/ha	1.13
Fertilizer rate	kg/ha	345.0
Herbicide rate	kg/ha	1.7
Seed price	$/kg	45.0
Fertilizer price	$/kg	0.41
Herbicide price	$/kg	20.0
Insecticide + Fungicide	$/kg	40.0
Sugar beet price	$/tonne	30.0
Sugar beet yield	tonne/ha	50.0

SOURCES: Michigan Statistical Abstract 1981. 16 ed. Detroit Bureau of Business Research, Wayne State University, April 1982, and pesonal communication with extension agents, and some local dealers.

3.4 Field Machinery

In order to study a crop production system, it is necessary to focus on field machinery as a major component of a farm system. The selection of field machinery, available in the market with their relevant prices, has to meet a set of interacting constraints including the following:

1. Crop to be grown
2. Field operations
3. Available machinery
4. Soil type (it was assumed to be medium textured soil)
5. Weather conditions
6. Production land area (it was assumed to be 200 ha)
7. Labor supply.

In this case, the mixed-integer linear programing model can compare different machinery sets and select the most economical one with respect to the existing constraints.

The kinds and sizes of field machinery chosen to be involved in navy beans, corn and sugar beet production are shown in Table 3-5.

TABLE 3-5

Kinds and Sizes of Implements
Used in the Models

Implements	Unit	Marketed in Michigan			
Tillage tractors	kw	59.7	89.5	119.3	
Utility tractor	kw	37.3			
Combines	m	4.0	5.0	5.6	
Windrowers	m	2.8	4.2	5.6	
Bean pullers	m	2.8	4.2	5.6	
Chisel plows	m	2.4	3.1	3.4	
Mold board plows	m	2.0	2.4	2.8	
Field cultivators	m	3.8	4.7	5.6	6.6
Sprayers	m	1.4	1.8	2.7	
Row planters	m	3.0	4.5	6.0	
Row cultivators	m	3.0	4.5	6.0	
Beet toppers	m	2.1	2.8		
Beet lifters	m	2.1	2.8		
Fertilizer spreader	m	3.0			

SOURCES: Official Guide, Michigan Equipment Dealers Association, Lansing, Michigan, 1982. Hannibal A. Muhtar, Dissertation for the degree of Ph.D., Michigan State University, 1982. Communication with dealers.

3.5 Machinery Cost Model

3.5-1 Model Description

The machinery cost model by Rotz et al. (1982) was used to calculate the cost of using the selected implements for navy beans, corn and sugar beet production. This program computes the total costs of owning and operating farm machines, tractors and trucks. The model includes the fixed costs of capital, interest, insurance, shelter, repairs and maintenance, and variable costs of fuel, lubrication and labor. Inflation is modeled for all costs with a separate rate used for machinery, fuel, and labor. Income tax deductions are modeled to include depreciation, interest, and operating cost along with an investment credit of 10 percent of the initial machine cost. Tax deductions are subtracted from the sum of all other costs to give a total cost. All machines are considered to be purchased with a loan and a 20 percent down payment. The term of the loan is set at 5 years with an interest rate of 12 percent per year.

This model was adopted to calculate the machinery cost because it deals with a cash flow method of analysis which is better suited than the fixed/variable cost method to model inflation's effect on costs since all costs are modeled as they occur.

In order to use the model it should be provided with appropriate input data which varies depending upon the type of machine to be analyzed. There are three major forms for the data to model the costs of either a tractor, or farm machinery. These data forms are listed below:

A. Tractor or self-propelled machine (type 2 or 3)

1. Machine code, name
2. New cost, age, power, annual use (hr), fuel type
3. (If used) purchase price, hours on machine

B. Implement (type 4 to 15)

1. Machine code, name
2. New cost, age, annual use (hr), width, speed
3. (If used) purchase price, hours on machine.

See Appendix D for further information about the model. The purchase prices of the selected implements are shown in Table 3-6.

The final purchase price estimates of the implements used in navy beans, corn, sugar beet production are shown in Table 3-7.

TABLE 3-6

Purchase Price of Selected Implements
(In Dollars Per Unit)

Implements	Unit	$/Unit
Tractor	kw	224.0
Bean puller	m	492.0
Chisel plow	m	1,312.0
Moldboard plow	m	2,707.0
Field cultivator	m	656.0
Row planter	m	1,969.0
Row cultivator	m	984.0
Beet topper	m	3,281.0
Beet lifter	m	7,218.0
Sprayer	m	2000.0 base price plus 66.0 per meter

SOURCES: Hannibal A. Muhtar, Dissertation for the degree of Ph.D., Michigan State University, 1982.

TABLE 3-7

Purchase Price of the Implements Involved
In Navy Bean, Corn, Sugar Beet
Production

Implements	Code	Unit	Size	Purchase P. $
Utility tractor	T_1	kw	37.3	8,355.00
Tillage tractor	T_2	kw	59.7	13,375.00
Tillage tractor	T_3	kw	89.5	20,000.00
Tillage tractor	T_4	kw	119.3	26,723.00
S.P. Combine	H_1	kw	108	59,090.00
S.P. Combine	H_2	kw	167.7	71,330.00
S.P. Combine with pickup H	H_3	kw	108	64,090.00
S.P. Combine with pickup H	H_4	kw	167.7	76,330.00
S.P. Combine with corn H.	H_5	kw	108	68,641.00
S.P. Combine with corn H.	H_6	kw	167.7	85,521.00
Pull-type windrower	W_1	m	2.8	4,500.00
Pull-type windrower	W_2	m	4.2	5,000.00
Pull-type windrower	W_3	m	5.6	5,500.00
Bean puller	B_1	m	2.8	1,377.00
Bean puller	B_2	m	4.2	2,065.00
Bean puller	B_3	m	5.6	2,755.00
Chisel plow	C_1	m	2.4	3,149.00
Chisel plow	C_2	m	3.1	4,068.00
Chisel plow	C_3	m	3.4	4,461.00
Moldboard plow	M_1	m	2.0	5,414.00
Moldboard plow	M_2	m	2.4	6,497.00
Moldboard plow	M_3	m	2.8	7,580.00
Field cultivator	F_1	m	3.8	2,492.80
Field cultivator	F_2	m	4.7	3,083.20
Field cultivator	F_3	m	5.6	3,673.60
Field cultivator	F_4	m	6.6	4,329.00

TABLE 3-7 Continued

Implements	Code	Unit	Size	Purchase P. $
Sprayer	S_1	m	1.4	2,092.00
Sprayer	S_2	m	1.86	2,122.00
Sprayer	S_3	m	2.77	2,183.00
Row planter	R_1	m	3.0	5,907.00
Row planter	R_2	m	4.5	8,860.00
Row planter	R_3	m	6.0	11,814.00
Row cultivator	V_1	m	3.0	2,952.00
Row cultivator	V_2	m	4.5	4,428.00
Row cultivator	V_3	m	6.0	5,900.00
Fertilizer spreader	Z_1	m	3.0	5,000.00
Beet topper	P_1	m	2.1	6,890.00
Beet topper	P_2	m	2.8	9,187.00
Beet lifter	L_1	m	2.1	15,158.00
Beet lifter	L_2	m	2.8	20,210.00

SOURCE: Robert G. White, Determining capacities of farm machines. E-1216. Cooperative Extension Service, Michigan State University, East Lansing, April 1978.

3.5-2 Model Results

The data required to execute the program were entered in the computer to calculate the following parameters for a ten year period:

1. Ownership cost
2. Repair and maintenance
3. Fuel
4. Total present value
5. Average annual cost

The calculation of labor cost was completed in the mixed-integer linear programing models rather than in the cost model. The reason for that is to allow the MILP models to compute the labor cost only when machinery was under field operation. In this case, more accurate results can be obtained. In the MILP model the labor cost was assumed to be 6.0 dollarc per hour. The summary of the selected implement costs are presented in Table 3-8.

3.6 Power Requirements

Obtaining a satisfactory match between tractor horsepower and implement size is an important phase of farm machinery management. Implements too large for available horsepower will cause tractor overloading, excessive tire slippage, a higher incidence of tractor breakdowns, and

TABLE 3-8

Summary of the Selected Implement Costs
(For Ten Year Period)

Implements	Code	Ownership Cost	Repair & Maintenance	Fuel	Total P. Value	Average Annual Cost
Utility Tractor	T_1	8,050.0	10,555.0	40,453.0	59,058.0	6,575.0
Tillage tractor	T_2	12,887.0	16,896.0	64,747.0	94,530.0	10,523.0
Tillage tractor	T_3	19,270.0	25,265.0	97,066.0	141,602.0	15,764.0
Tillage tractor	T_4	25,789.0	33,814.0	129,598.0	189,202.0	21,063.0
S.P. Combine	H_1	55,924.0	19,001.0	15,930.0	90,855.0	10,115.0
S.P. Combine	H_2	67,508.0	22,937.0	24,735.0	115,180.0	12,822.0
S.P. Combine with pickup	H_3	60,656.0	20,609.0	15,930.0	97,195.0	10,820.0
S.P. Combine with pickup	H_4	72,240.0	24,545.0	24,735.0	121,520.0	13,528.0
S.P. Combine with corn H.	H_5	64,963.0	44,191.0	23,426.0	132,580.0	14,760.0
S.P. Combine with corn H.	H_6	80,939.0	55,058.0	36,375.0	172,373.0	19,190.0
Pull-type windrower	W_1	3,671.7	2,502.0	0.0	6,174.0	686.0
Pull-type windrower	W_2	4,130.7	2,817.3	0.0	6,948.0	772.0
Pull-type windrower	W_3	4,589.7	3,132.3	0.0	7,722.0	858.0
Bean puller	B_1	1,264.0	1,276.0	0.0	2,540.0	283.0
Bean puller	B_2	1,896.0	1,130.0	0.0	3,026.0	337.0
Bean puller	B_3	2,530.0	1,037.0	0.0	3,566.0	397.0
Chisel plow	C_1	2,891.0	1,244.0	0.0	4,136.0	460.0
Chisel plow	C_2	3,735.0	1,041.0	0.0	4,749.0	529.0
Chisel plow	C_3	4,096.0	942.0	0.0	5,038.0	561.0
Moldboard plow	M_1	4,971.0	5,604.0	0.0	10,575.0	1,177.0
Moldboard plow	M_2	5,965.0	5,306.0	0.0	11,271.0	1,255.0
Moldboard plow	M_3	6,960.0	5,066.0	0.0	12,026.0	1,339.0
Field cultivator	F_1	2,288.0	431.0	0.0	2,719.0	303.0
Field cultivator	F_2	2,831.0	363.0	0.0	3,194.0	356.0
Field cultivator	F_3	3,372.0	316.0	0.0	3,688.0	411.0
Field cultivator	F_4	3,973.0	279.0	0.0	4,253.0	474.0

TABLE 3-8 Continued

Implements	Code	Ownership Cost	Repair & Maintenance	Fuel	Total P. Value	Average Annual Cost
Sprayer	S_1	1,920.0	1,920.0	0.0	3,398.0	378.0
Sprayer	S_2	1,948.0	1,566.0	0.0	3,515.0	391.0
Sprayer	S_3	2,004.5	1,609.6	0.0	3,614.1	402.0
Row planter	R_1	5,424.0	5,128.0	0.0	10,552.0	1,175.0
Row planter	R_2	8,135.0	4,020.0	0.0	12,155.0	1,353.0
Row planter	R_3	10,847.0	3,383.0	0.0	14,230.0	1,584.0
Row cultivator	V_1	2,710.0	1,620.0	0.0	4,330.0	482.0
Row cultivator	V_2	4,066.0	1,171.0	0.0	5,237.0	583.0
Row cultivator	V_3	4,591.0	1,981.0	0.0	6,571.0	732.0
Fertilizer spreader	Z_1	4,591.0	1,363.0	0.0	5,953.0	663.0
Beet topper	P_1	7,571.0	4,327.0	0.0	11,899.0	1,322.0
Beet topper	P_2	10,095.0	5,773.0	0.0	15,868.5	1,763.0
Beet lifter	L_1	16,657.0	9,569.0	0.0	26,226.0	2,914.0
Beet lifter	L_2	22,208.0	12,846.0	0.0	35,055.0	3,895.0

unsatisfactory performance in general. Implements that are too small will result in inefficient operation, low production, and increased costs.

Due to the wide range of implements used in navy bean, corn, and sugar beet production, it is impossible to match all implements perfectly to the tractor horsepower available. Therefore, the objective is to match as effectively as possible the tractor power available and the power requirements of the majority of the "heavy draft" machines.

The PTO power requirement for the selected implements in medium-textured soil were calculated depending upon the following parameters:

1. Type of soil
2. Implement width
3. Implement speed
4. Depth of plowing (for tillage implements)
5. Draft force per unit width kw/m

Table 3-9 represents the power requirement (kw/m) for selected implements in medium textured soil. The final results for the power requirements, for the implements contributing in navy bean, corn, and sugar beet production systems, in medium textured soil, are presented in Table 3-10. The machine capacities (ha/hr) for selected

TABLE 3-9

Power Requirement for Implements
in Medium-Textured Soil

Implements	PTO power kw/m
Bean puller	7.31
Windrower	4.00
Chisel plow	24.40
Moldboard plow	27.90
Row planter	8.8
Sprayer	3.6
Row cultivator	7.2
Beet topper	9.8
Beet lifter	39.1

Modified from: Donnell Hunt, Farm Power and Machinery Management, Iowa State University Press, Ames, Iowa. 1979. Hannibal A. Muhtar, Dissertation for Degree of Ph.D., Michigan State University, 1982.

TABLE 3-10

Power Requirements for Selected Implements in Medium-Textured Soil and the Relevant Tractor Sizes

Implements	Code	Size (m)	PTO power (kw)	Tractor Size (kw)	Code
Bean puller	B_1	2.8	20.46		
Bean puller	B_2	4.2	30.70		
Bean puller	B_3	5.6	40.93		
Bean windrower	W_1	2.8	11.20		
Bean windrower	W_2	4.2	16.80		
Bean windrower	W_3	5.6	22.40		
Puller & windrower	$B_1 + W_1$	2.8	31.66	37.3	T_1
Puller & windrower	$B_2 + W_2$	4.2	47.5	59.7	T_2
Puller & windrower	$B_3 + W_3$	5.6	63.3	89.5	T_3
Chisel plow	C_1	2.4	58.56	59.7	T_2
Chisel plow	C_2	3.1	75.64	89.5 or 119.3	T_3, T_4
Chisel plow	C_3	3.4	82.96	89.5 or 119.3	T_3, T_4
Moldboard plow	M_1	2.0	55.8	59.7	T_2
Moldboard plow	M_2	2.4	66.96	89.5 or 119.3	T_3, T_4
Moldboard plow	M_3	2.8	78.12	89.5 or 119.3	T_3, T_4
Field cultivator	F_1	3.8	32.49	37.3	T_1
Field cultivator	F_2	4.7	40.185	59.7	T_2
Field cultivator	F_3	5.6	47.88	59.7	T_2
Field cultivator	F_4	6.6	56.43	59.7	T_2
Sprayer	S_1	1.4	5.04	37.3	T_1
Sprayer	S_2	1.86	6.7	37.3	T_1
Sprayer	S_3	2.77	10.0	37.3	T_1
Row planter	R_1	3.0	26.40	37.3	T_1
Row planter	R_2	4.5	39.60	59.70	T_2
Row planter	R_3	6.0	52.7	59.70	T_2

TABLE 3-10 Continued

Implements	Code	Size (m)	PTO power (kw)	Tractor Size (kw)	Code
Row cultivator	V_1	3.0	21.80	37.3	T_1
Row cultivator	V_2	4.5	32.40	37.3	T_1
Row cultivator	V_3	6.0	43.20	59.67	T_2
Fertilizer spreader	Z_1	3.0	11.1	37.3	T_1
Beet topper	P_1	2.1	20.58	37.3	T_1
Beet topper	P_2	2.8	27.44	37.3	T_1
Beet lifter	L_1	2.1	82.11	119.3	T_4
Beet lifter	L_2	2.8	109.48	119.3	T_4

implements are shown in Table 3-11. Figures 3-1, 3-2 and 3-3 represent the possible ways of matching implements with selected tractor sizes (37.34, 59.7, 89.5 and 119.3 kw). For example, Tractor 1 (T_1) can match in the MILP model with implements in one of twelve ways depending upon the size of implement required to cover 200 ha of land.

3.7 Predicting the Number of Suitable Days for Field Work

Timing field operations is an important part of successful crop production. The effects of untimely operations could influence management decisions involving the selection of machinery and labor systems.

The variation in weather from year to year and its resultant impact on the number of good days available for soil preparation, planting, spraying, cultivation and harvest has been a major uncertainty in making good selection and choices. Therefore, the manager's ability to make proper system selections and to schedule men and machines depends to a high degree on his ability to predict available working time in the field during any part of the crop season.

TABLE 3-11

Machine Capacities (ha/hr) for Selected Implements

Implements	Code	Efficiency (%)	Width (m)	Speed (km/hr)	Capacity (ha/hr)
S.P. Combine	H_1, H_5	65	4.0	4.8	1.25
S.P. Combine	H_2, H_6	65	5.0	4.8	1.56
*S.P. Combine with pickup	H_3	65	5.6	6.0	2.18
**S.P. Combine with pickup	H_4	65	7.0	6.0	2.73
B. windrower	W_1	80	2.8	5.6	1.17
B. windrower	W_2	80	4.2	5.6	1.76
B. windrower	W_3	80	5.6	5.6	2.35
Bean puller	B_1	80	2.8	5.6	1.17
Bean puller	B_2	80	4.2	5.6	1.76
Bean puller	B_3	80	5.6	5.6	2.35
Chisel plow	C_1	85	2.4	7.2	1.468
Chisel plow	C_2	85	3.1	7.2	1.897
Chisel plow	C_3	85	3.4	7.2	2.08
Moldboard plow	M_1	80	2.0	7.2	1.15
Moldboard plow	M_2	80	2.4	7.2	1.38
Moldboard plow	M_3	80	2.8	7.2	1.61
Field cultivator	F_1	90	3.8	7.2	2.46
Field cultivator	F_2	90	4.7	7.2	3.00
Field cultivator	F_3	90	5.6	7.2	3.62
Field cultivator	F_4	90	6.6	7.2	4.62
Sprayer	S_1	65	1.4	8.1	.73
Sprayer	S_2	65	1.86	8.1	.97
Sprayer	S_3	65	2.77	8.1	1.45
Row planter	R_1	60	3.0	8.1	1.45
Row planter	R_2	60	4.5	8.1	2.18
Row planter	R_3	60	6.0	8.1	2.91

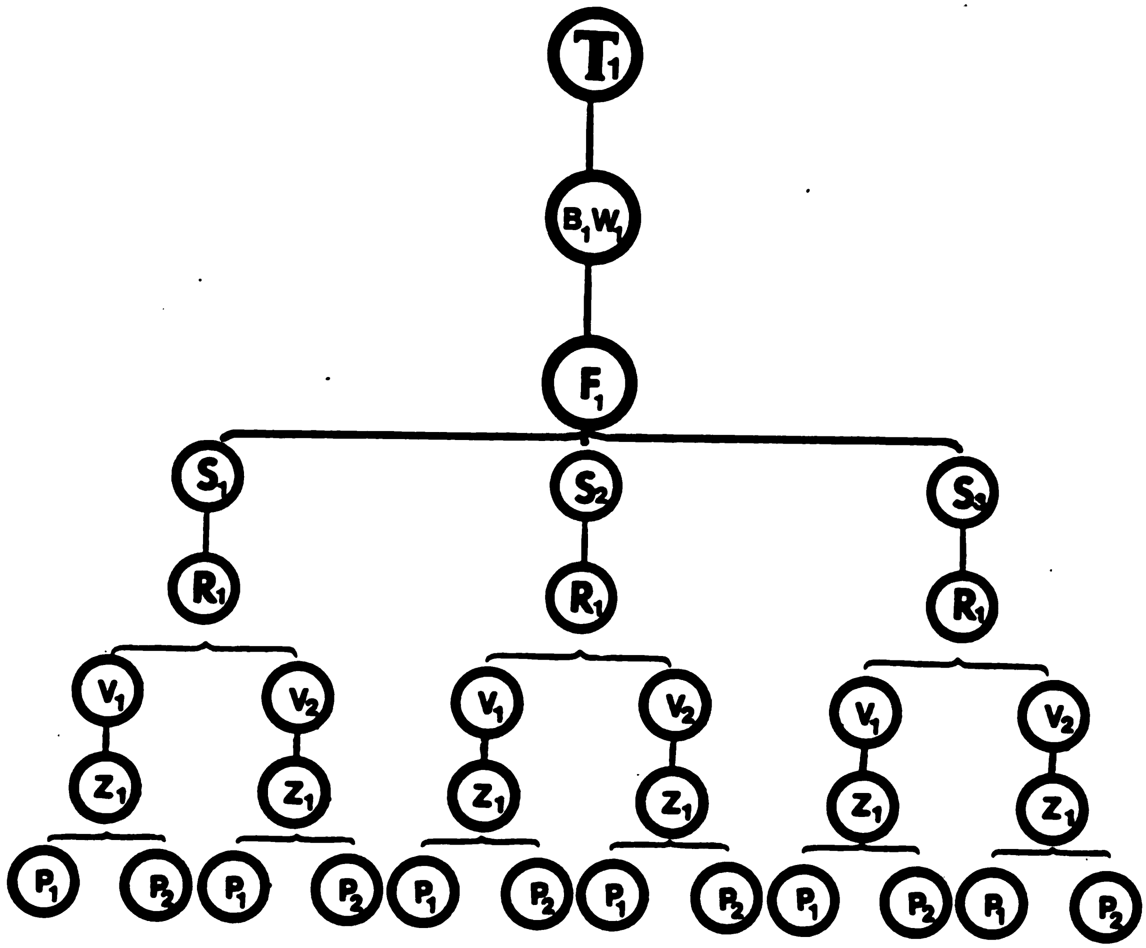
TABLE 3-11 Continued

Implements	Code	Efficiency (%)	Width (m)	Speed (km/hr)	Capacity (ha/hr)
Row cultivator	V_1	85	3.0	4.8	1.22
Row cultivator	V_2	85	4.5	4.8	1.83
Row cultivator	V_3	85	6.0	4.8	2.44
Fertilizer spreader	Z_1	80	3.0	7.2	1.72
Beet topper	P_1	70	2.1	4.8	.7
Beet topper	P_2	70	2.8	4.8	.94
Beet lifter	L_1	70	2.1	4.8	.7
Beet lifter	L_2	70	2.8	4.8	.94

SOURCE: Robert G. White, Determining Capacities of Farm Machines. E-1216. Cooperative Extension Service, Michigan State University, East Lansing. April 1978.

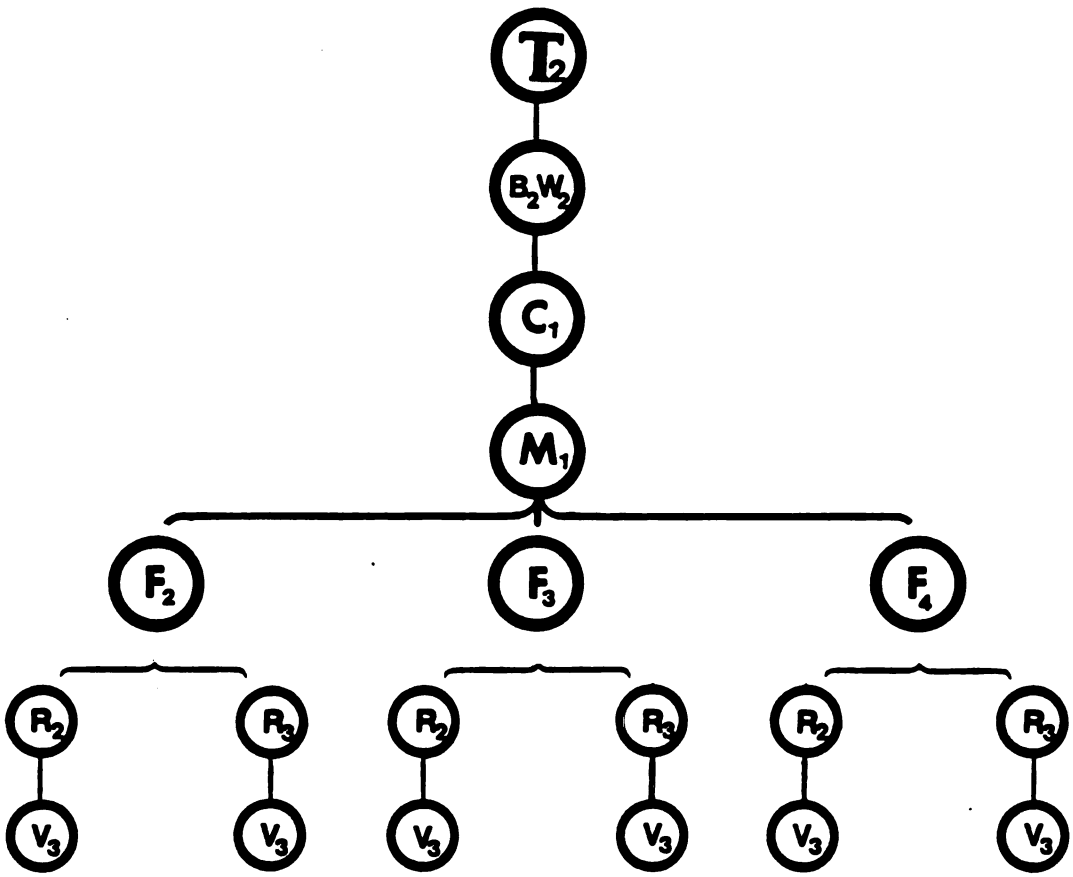
* SP Combine (H_3-4.0 m) was assumed to pickup a windrwo of navy bean plants windrowed from 8 rows (5.6 m).

**SP Combine (H_4-5.0 m) was assumed to pick up a windrow of navy bean plants windrowed from 10 rows (7.0 m).



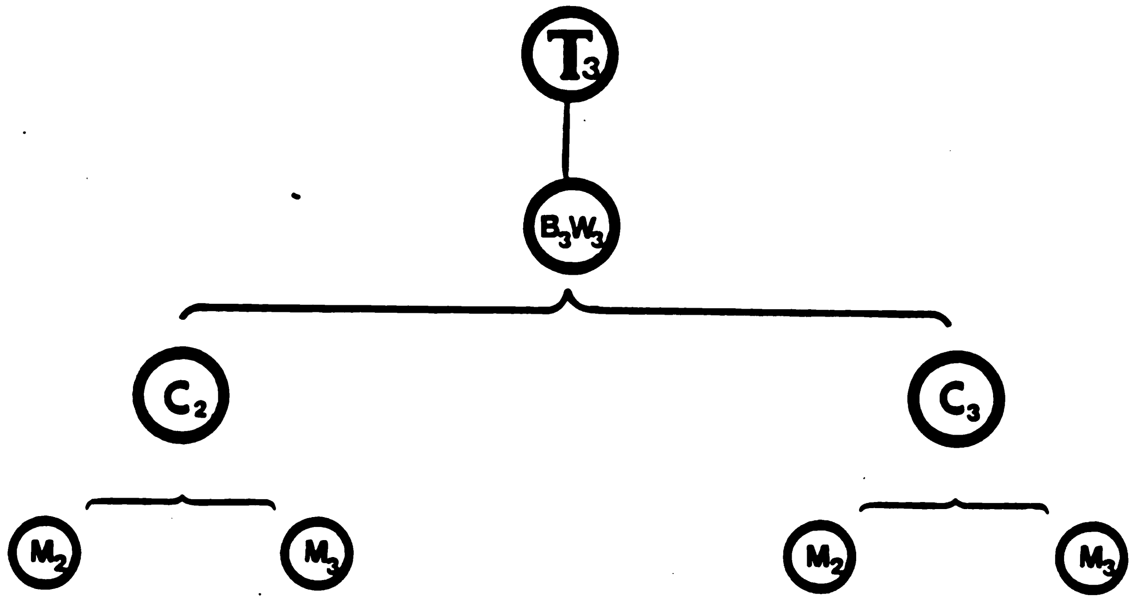
B1,W1 : Bean puller 1, Windrower 1
F1 : Field cultivator
S1,2,3 : Sprayer 1,2,3
R1 : Row planter 1
V1,2 : Row cultivator 1,2
Z1 : Fertilizer spreader
P1,2 : Beet topper 1,2

Fig. 1 Possible ways of matching tractor 1 (T1) and selected implements.



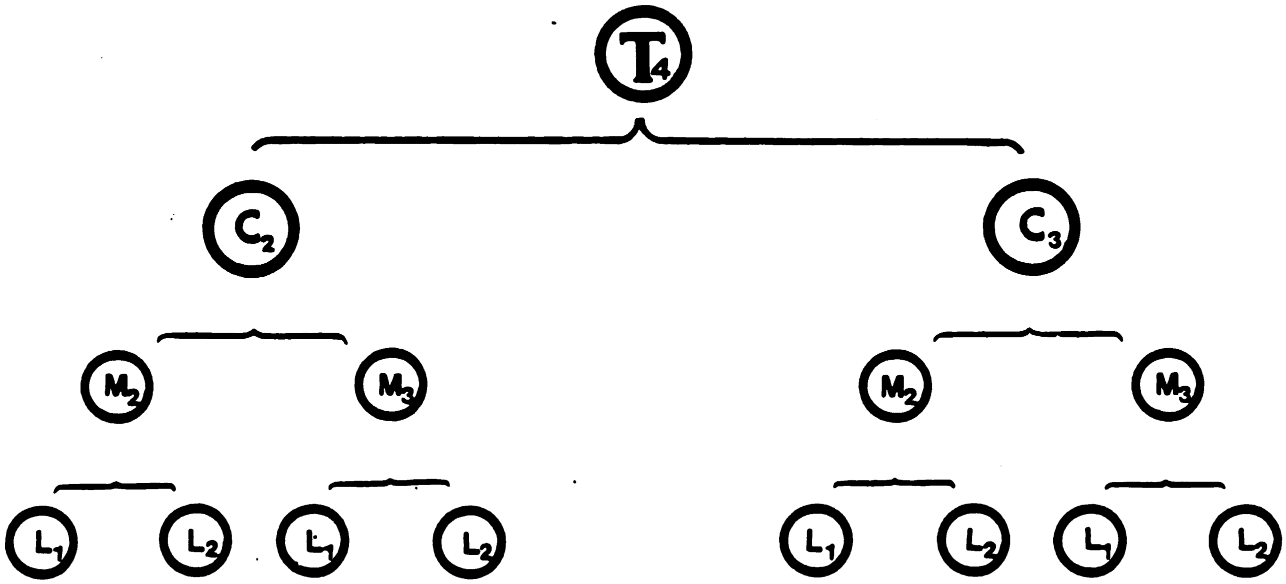
B2, W2 : Puller 2, Windrower 2
C1 : Chisel plow 1
M1 : Moldboard plow 1
F2,3,4 : Field cultivator 2,3,4
R2,3 : Row planter 2,3
V3 : Row cultivator 3

Fig. 2 Possible ways of matching tractor 2 (T2) and selected implements.



B3, W3 : Puller 3, Windrower 3
C2 : Chisel plow 2
M2,3 : Moldboard plow 2,3
F3,4 : Field cultivator 3,4

Fig. 3 The possible ways of matching tractor 3 (T3) and selected implements.



C2,3 : Chisel plow 2,3
M2,3 : Moldboard plow 2,3
L1,2 : Beet lifter 1,2

Fig. 4 The possible ways of matching tractor 4 (T4) and selected implements.

Rotz et al. (1982) developed an algorithm to provide suitable days data for different locations in Michigan. The results of this model has been found to have less than 15 percent error.

In this particular study, the predication of suitable days for field work in Michigan conducted by Rotz et al. (1982) was used in the MILP models to compute the number of the available hours for field work in Saginaw. Table 3-12 represents the predicted portion of days for field work in Saginaw at .8 probability level. (A probability level of 0.8 indicates that 8 years or more out of 10 the portion of the days indicated will be suitable.) The number of hours available for field work at 0.8 probability level for navy beans, corn and sugar beets were calculated as follows:

1. The calendar days within which field operations can be performed were organized depending upon the weather history of Michigan and some recommendaitons from specialists.
2. The actual number of days available for field work were calculated by multiplying the available days for executing each field operation by the corresponding portion of days suitable for field work.

TABLE 3-12

Predicted Portion of Days Suitable for Field Work in Saginaw at a 0.8 Level of Probability

Period	Portion of days
1- Nonharvest operations	
April 20 - 30	.34
May 1 - 10	.66
May 11 - 20	.62
May 21 - 31	.71
June 1 - 15	.66
June 16 - 30	.72
July 1 - 15	.80
July 16 - 31	.79
Aug. 1 - 15	.65
Aug. 16 - 31	.71
Sept. 1 - 15	.75
Sept. 16 - 30	.68
Oct. 1 - 15	.64
Oct. 16 - 31	.58
Nov. 1 - 15	.42
Nov. 16 - 30	.11
2- Harvest operations	
Sept. 1 - 15	.53
Sept. 16 - 31	.45
Oct. 1 - 15	.49

SOURCE: C. Alan Rotz et al. "Prediction of suitable days for field work." Michigan State University, 1982.

3. The actual number of hours available for field work were then calculated by multiplying the number of actual days available for field work by the corresponding number of hours per day within which each field operation can be performed.
4. Each number of hours available for a field operation was then compared with the recommended hours for a machine to execute the field work. If the recommended number of hours were less than the calculated hours, the recommended hours would be used in the MILP models; otherwise the calculated number of hours would be taken into consideration.

Table 3-13 summarizes the number of hours per day within which field operations can be performed. The final results of the calculated number of hour available for field work at probability .8 for navy beans, corn, and sugar beets are presented in Tables 3-14, 3-15 and 3-16 respectively. The estimated life of selected farm machinery are listed in Table 3-17.

TABLE 3-13

Number of Hours Assigned to Field Operation

Operation	Number of Hours per Day
Fall plowing	12
Fertilizer application	12
Field cultivation	12
Planting	12
Row cultivation	12
Spraying	12
Direct harvesting beans	8
Convent. harvesting beans	10
Corn harvesting	10
Sugar beet harvesting	12

SOURCE: Francis J. Wolak "Development of a field machinery selection model." Dissertation for the degree of Ph.D., Michigan State University 1981.

TABLE 3-14

Calendar Days and Number of Available Hours
for Field Work at 0.8 Probability Level
for Bean Production

Operation	Execution Date	Number of Hours
Fall plowing	10/9 to 11/27	135.0
Fertilizer application	5/1 to 5/15	121.0
Spring cultivation	5/9 to 5/29	160.0
*Planting	5/30 to 6/19	154.0 (80.0)
Row cultivation	6/20 to 7/5	135.0
Spraying	6/20 to 7/5	135.0
Direct harvesting beans	9/5 to 10/10	153.0
Convent. harvesting beans	9/10 to 10/20	192.0
- Pulling and windrow		96.0
- Combining		96.0

SOURCE: Francis J. Wolak "Development of a field machinery selection model." Dissertation for the degree of Ph.D., Michigan State University 1981.

*When average annual use exceeds the recommended number of hours, machine will wear out before it becomes obsolete.

TABLE 3-15

Calendar Days and Number of Available Hours for Field Work at 0.8 Probability Level for Corn Production

Operation	Execution Date	Number of Hours
Fall plowing	10/9 to 11/27	135.0
Fertilizer application	10/9 to 11/27	135.0
Spring cultivation	4/20 to 5/10	120.0
*Planting	4/24 to 5/10	160.0 (80.0)
Spraying	4/15 to 5/15	165.0
Row cultivation	6/1 to 6/18	144.0
Harvesting	10/10 to 11/12	153.0

SOURCE: Francis J. Wolak "Development of a field machinery selection model." Dissertation for the degree of Ph.D., Michigan State University 1981.

*When average annual use exceeds the recommended number of hours, machine will wear out before it becomes obsolete.

TABLE 3-16

Calendar Days and Number of Available Hours
for Field Work at 0.8 Probability Level
for Sugar Beet Production

Operation	Execution Date	Number of Hours
Fall plowing	10/25 to 11/25	124.0
Spring cultivation	4/10 to 5/10	160.0
*Planting	4/15 to 5/15	*(80.0)
Spraying	5/22 to 6/12	163.0
Row cultivation	5/22 to 6/12	163.0
Harvesting	10/1 to 11/13	230.0

SOURCE: Francis J. Wolak "Development of a field machinery selection model." Dissertation for the degree of Ph.D., Michigan State University 1981.

*Recommended number of hours for using planter.

TABLE 3-17

The Estimated Life of Machines

Machine	Years Until Obsolete	Wear Out Life Hours	Hours per Year for Wear Out Life to Equal Obsolescence Life*
Tractors			
Wheel-type	10	1000	1000
Track-type	15	15000	1000
Tillage implements			
Cultivators	12	2500	208
Moldboard plow	15	2500	167
Seeders			
Grind drill	15	1200	80
Row crop planer	15	1200	80
Harvesting equipment			
Combine, S.P.	10	2000	200
Sugar beet harvester	10	2500	250
Windrower	10	2500	250
Fertilizer equipment	8	1200	150

SOURCE: R.A. Keeper, R. Bainer and E.L. Eager, Principles of farm machinery. AVI Publ. Co., Inc., Third Ed., 1978.

*When average annual use exceeds this number of hours, machine will wear out before it becomes obsolete.

4 NAVY BEAN PRODUCTION MODEL

4.1 Model Formulation

The algorithm which follows was developed to evaluate and compare navy bean production systems in Michigan involving conventional and direct harvest methods. A mixed integer linear programming model was formulated with 44 columns (activities) and 38 rows (constraints) to select the navy bean variety to recommend (Swan Valley or Fleetwood), the planting system to follow (wide rows or narrow rows), the harvesting method to apply (direct or conventional), and finally the number and type of farm machinery to use so that the profit can be maximized. The following equations overview the navy ean MILP model structure:

The objective function:

$$
\begin{aligned}
\text{Maximize } Z = & - X_1WD_1 - X_2WD_2 - X_3WC_3 - X_4SD_1 - X_5SD_2 \\
& - X_6SC_3 - X_7D_1 - X_8E_1 - X_9H_1 - X_{10}T_1 \\
& - X_{11}T_2 - X_{12}T_3 - X_{13}M_1 - X_{14}M_2 - X_{15}M_3 \\
& - X_{16}C_1 - X_{17}C_2 - X_{18}C_3 - X_{19}Z_1 - X_{20}F_1 \\
& - X_{21}F_2 - X_{22}F_3 - X_{23}F_4 - X_{24}R_1 - X_{25}R_2 \\
& - X_{26}R_3 - X_{27}V_1 - X_{28}V_2 - X_{29}V_3 - X_{30}S_1 \\
& - X_{31}S_2 - X_{32}S_3 - X_{33}B_1 - X_{34}B_2 - X_{35}B_3 \\
& - X_{36}W_1 - X_{37}W_2 - X_{38}W_3 - X_{39}H_1 - X_{40}H_2 \\
& - X_{41}H_3 - X_{42}H_4 - X_{43}La - X_{44}SB
\end{aligned}
$$

where Z : The total net profit for the selected navy bean production system.

where Xn : Level of activity n for n = 1 . . . 44 (column number)

WD_1 : Insecticide and fungicide cost \$/ha for Fleetwood planted in 35 cm row spacing and directly harvested

WD_2 : Insecticide and fungicide cost \$/ha for Fleetwood variety planted in 70 cm row spacing and directly harvested

WC_3 : Insecticied and fungicide cost \$/ha for Fleetwood variety planted in 70 cm row spacing and conventionally harvested

SD_1 : Insecticide and fungicide cost \$/ha for Swan Valley variety planted in 35 cm row spacing and directly harvested

SD_2 : Insecticide and fungicide cost \$/ha for Swan Valley variety planted in 70 cm row spacing and directly harvested

SC_3 : Insecticide and fungicide cost \$/ha for Swan valley variety planted in 70 cm row spacing and conventionally harvested

D_1 : The navy bean seed price \$/kg

E_1 : The fertilizer cost \$/kg

H_1 : The herbicides cost \$/kg

Table 3-1 represents the summary of navy bean production data used in the navy bean MILP model.

T_m : The annual cost of using tractor m \$/yr where

$m = 1,2,3$

M_m : The annual cost of using moldboard plow m \$/yr where

$m = 1,2,3$

C_m : The annual cost of using chisel plow m \$/yr where

$m = 1,2,3$

Z_1 : The annual cost of using the fertilizer spreader

\$/yr

F_m : The annual cost of using field cultivator m \$/yr

where $m = 1,2,3,4$

R_m : The annual cost of using row planter m \$/yr where

$m = 1,2,3$

V_m : The annual cost of using row cultivator m \$/yr where

$m = 1,2,3$

S_m : The annual cost of using sprayer m \$/yr where

$m = 1,2,3$,

B_m : THe annual cost of using bean puller m \$/yr where

$m = 1,2,3$

W_m : The annual cost of using windrower m \$/yr where

$m = 1,2,3$

H_m : The annual cost of using harvester m \$/yr where

$m = 1,2,3,4$

Table 3-8 summarizes the total annual costs for each implement used in the navy bean MILP model

La : The labor cost per hour \$/hr

SB : The market sale price of navy beans \$/kg.

The objective function (net profit) was maximized subject to a series of constraints illustrated by relationships 4-1 through 4-38 where the equation numbers represent the constraing number, and the subscripted X's value show the columns (activity) number.

Land constraint:

$$X_1a_1 + X_2a_2 + X_3a_3 + X_4a_4 + X_5a_5 + X_6a_6 \leq b_1 \quad (4\text{-}1)$$

where:

X_n : Represents the level of activity n (land area) which the computer is going to assign for the selected navy bean variety where n = 1, . . .6 (column's number)

a_n : Is a vector (value) of ones (under three systems of Fleetwood variety and three systems of Swan Valley variety see Appendix A-1 row 4) where n = 1, . . . 6 (activity number)

b_1 : Is the land area limitation (it was set to be 200 ha)

Yield constraint:

$$- X_1Y_1 - X_2Y_2 - X_3Y_3 - X_4Y_4 - X_5Y_5 - X_6Y_6 + X_{44}Y_{44} \leq 0 \quad (4\text{-}2)$$

where:

X_n : Is the level of activity n (size of Land in ha) where n = 1, . . .6

X_{44} : Is the level of selling activity (the yield going to be sold)

Y_n : Is the yield kg/ha (for the Fleetwood under three systems and Swan Valley under three systems) where n = 1, . . . 6

Y_{44} : Is a vector of 1 under selling activity

Seeding rate constraint:

$$X_1Se_1 + X_4Se_4 - X_7Se_7 \leq 0 \qquad (4\text{-}3)$$

where:

X_n : Level of activity n (size of land in ha) where n = 1, 4, 7

Se_m: The amount of seed required (kg/ha) for navy beans planted in 35 cm row spacing where m = 1,4

Se_7: Is a vector of -1 (avalue of -1 under column 7, the seed price $/kg)

Seeding rate constraint:

$$X_2Se_2 + X_3Se_3 + X_5Se_5 + X_6Se_6 - X_7Se_7 \leq 0 \qquad (4\text{-}4)$$

where:

X_n : Level of activity n (size of land in ha) where n = 2, 3, 5, 6, 7

Se_m: The amount of seed required (kg/ha) for beans planted in 70 cm row spacing where m = 2, 3, 5, 6

Se_7: Is a vector of -1 (a value of -1 under column 7, the seed price $/kg)

Fertilizer rate constraint:

$$X_1Fe_1 + X_2Fe_2 + X_3Fe_3 + X_4Fe_4 + X_5Fe_5 + X_6Fe_6 - X_8Fe_8 \leq 0 \qquad (4\text{-}5)$$

where:

X_n : Level of activity n (size of land) where n = 1, 2, 3, 4, 5, 6, 8

Fe_m: The amount of fertilizer required (kg/ha) where m = 1, . . . 6

Fe_8: Is a vector of -1

Herbicide rate constraint:

$$X_1He_1 + X_2He_2 + X_3He_3 + X_4He_4 + X_5He_5 + X_6He_6 - X_9He_9 \leq 0 \qquad (4\text{-}6)$$

where:

X_n : Level of activity n (size of land in ha) where n = 1, . . . 6 and 9 (column number)

He_m : The amount of herbicides requied (kg/ha) where m = 1, . . . 6

He_9 : Is a vector of -1 (a value of -1 under column 9 the herbicide price \$/kg)

<u>Plowing operation</u>:

$$X_1PO_1 + X_2PO_2 + X_3PO_3 + X_4PO_4 + X_5PO_5 + X_6PO_6 - X_{13}PO_{13} - X_{14}PO_{14} - X_{15}PO_{15} - X_{16}PO_{16} - X_{17}PO_{17} - X_{18}PO_{18} \leq 0 \qquad (4\text{-}7)$$

where:

X_n : Level of activity n (number of tillage implements) where n = 1, . . . 6 and 13, . . . 18 (column number)

PO_m : Is a vector of ones where m = 1, . . . 6

PO_k : Is a matris of the number of hectares that each tillage implement can cover during the tillage time where K = 13, . . . 18 (the number of hectares that tillage implement k can cover during tillage time was calculated by multiplying the implement capacity ha/hr by the number of hours available for field work.)

<u>Applying fertilizer</u>:

$$X_1F_1 + X_4F_4 - X_{19}F1_{19} \leq 0 \qquad (4\text{-}8)$$

where:

X_n : Level of activity n (number of fertilizer spreaders) where n = 1, 4, 19 (column number)

f_m : Is a vector of ones where m = 1, 4 (for beans planted in narrow rows)

f_{19}: The number of hectares that the fertilizer spreader can cover during the application time.

<u>Field cultivation:</u>

$$X_1ha_1 + X_2ha_2 + X_3ha_3 + X_4ha_4 + X_5ha_5 + X_6ha_6$$
$$- X_{20}ha_{20} - X_{21}ha_{21} - X_{22}ha_{22} - X_{23}ha_{23} \leq 0 \qquad (4\text{-}9)$$

where:

X_n : Level of activity n (number of field cultivators) where n = 1, . . . 6 and 20, . . . 23

ha_m: Is a vector of ones where m = 1, . . . 6

ha_k: The number of hectares that field cultivator k can cover during the field cultivation time, where K = 20, 23

<u>Planting operation:</u>

$$X_1PL_1 + X_2PL_2 + X_3PL_3 + X_4PL_4 + X_5PL_5 + X_6PL_6$$
$$- X_{24}PL_{24} - X_{25}PL_{25} - X_{26}PL_{26} \leq 0 \qquad (4\text{-}10)$$

where:

X_n : Level of activity n (number of row planters) where n = 1, . . . 6 and 24, . . . 26

PL_m: Is a vector of ones where M = 1, . . . 6

PL_k: The number of hectares that row planter k can cover during planting time, where k = 24, . . . 26

Row cultivation:

$$X_2Cu_2 + X_3Cu_3 + X_5Cu_5 + X_6Cu_6 - X_{27}Cu_{27}$$
$$- X_{28}Cu_{28} - X_{29}Cu_{29} \leq 0 \qquad (4\text{-}11)$$

where:

X_n : Level of activity n (number of row cultivators) where n = 2, 3, 5, 6, 27, 28, 29

Cu_m: Vector of ones for beans planted in wide row system where m = 2, 3, 5, 6

Cu_k: The number of hectares that row cultivator k can cover during the cultivating time where k = 27, ... 29

Spraying operation:

$$X_1SP_1 + X_2SP_2 + X_3SP_3 + X_4SP_4 + X_5SP_5 + X_6SP_6$$
$$- X_{30}SP_{30} - X_{31}SP_{31} - X_{32}SP_{32} \leq 0 \qquad (4\text{-}12)$$

where:

X_n : Level of activity n (number of sprayers) where n = 1, . . . 6 and 30, . . . 32

SP_m: A vector of ones for m where m = 1, . . . 6

SP_k: The number of hectares that sprayer k can cover during spraying time where k = 31, . . . 33

Bean pulling operation:

$$X_3Pu_3 + X_6Pu_6 - X_{33}Pu_{33} - X_{34}Pu_{34}$$
$$- X_{35}Pu_{35} \leq 0 \qquad (4\text{-}13)$$

where:

X_n : Level of activity n (number of bean pullers) where n = 3,6,33,34,35

Pu_m: A vector of ones for m where m = 3, 6 (only for beans planted in 70 cm and conventionally harvested)

Pu_k: The number of hectares that bean puller k can cover during pulling time where k = 33, 34, 35

<u>Windrowing operation:</u>

$$X_3Wn_3 + X_6Wn_6 - X_{36}Wn_{36} - X_{37}Wn_{37} - X_{38}Wn_{38} \leq 0 \quad (4\text{-}14)$$

where:

X_n : Level of activity n (number of windrowers) where n = 3, 6, 36, 37, 38

Wn_m: A vector of ones for m = 3, 6 (only for beans planted in 70 cm and conventionally harvested)

Wn_k: The number of hectares that windrower k can cover during windrowing times where k = 36, 37, 38

<u>Combining operation:</u>

$$X_3Co_3 + X_6Co_6 - X_{41}Co_{41} - X_{42}Co_{44} \leq 0 \quad (4\text{-}15)$$

where:

X_n : Level of activity n (number of harvesters) where n = 3, 6, 41, 42

Co_m: A vector of ones for m = 3, 6 (only for beans planted in 70 cm and conventionally harvested)

Co_k: The number of hectares that harvester k with pick-up header can cover during combining time, where k = 41, 42

<u>Harvesting operation:</u>

$$X_1hr_1 + X_2hr_2 + X_4hr_4 + X_5hr_5 - X_{39}hr_{39} - X_{40}hr_{40} \leq 0 \quad (4\text{-}16)$$

where:

X_n : Level of activity n (number of harvesters) where n = 1,2,4,5,29,40

hr_m: A vector of ones for m = 1,2,4,5, (only for beans harvested directly)

hr_k: The number of hectares that harvester k can cover during harvesting time where k = 39, 40

<u>Usage of tractor 1:</u>

$$- X_{10}Ta_{10} + X_{19}Ta_{19} + X_{20}Ta_{20} + X_{24}Ta_{24} + X_{27}Ta_{27} + X_{28}Ta_{28} + X_{30}Ta_{30} + X_{31}Ta_{31} + X_{32}Ta_{32} + X_{33}Ta_{33} \leq 0 \qquad (4\text{-}17)$$

where:

X_n : Level of activity n (number of implements)

Ta_{10} : The recommended annual number of hours for tractor 1 to be used for executing field operation: (it was assumed to be 1,000 hrs.)

Ta_m: The number of hours under which each field operation can be performed by tractor 1 using implement m where m = 19, 20, 24, 27, 28, 30, 31, 32, 33. (The number of horus under which a field operation can be performed were calculated by dividing the land area (200 ha was assumed in this model) by the implement capacity ha/hr).

<u>Usage of tractor 2:</u>

$$- X_{11}Ta_{11} + X_{13}Ta_{13} + X_{16}Ta_{16} + X_{21}Ta_{21} + X_{22}Ta_{22} + X_{23}Ta_{23} + X_{25}Ta_{25} + X_{26}Ta_{26} + X_{29}Ta_{29} + X_{34}Ta_{34} \leq 0 \qquad (4\text{-}18)$$

where:

X_n : Level of activity n (number of implements)

Ta_{11}: The recommended annual number of hours for tractor 2 to be used for executing field operation: (the number of hours were assumed to be 1,000).

Ta_m: The number of hours under which each field operation can be performed by tractor 2 using implement m, where m = 13, 16, 21, 22, 23, 29 and 34.

<u>Usage of tractor 3:</u>

$$- X_{12}Ta_{12} + X_{14}Ta_{14} + X_{15}Ta_{15} + X_{17}Ta_{17} + X_{18}Ta_{18} + X_{35}Ta_{35} \leq 0 \qquad (4\text{-}19)$$

where:

X_n : Level of activity n (number of implements)

Ta_{12}: The recommended annual number of hours for tractor 3 to be used for executing field operations (the number of hours were assumed to be 1,000).

Ta_m : The number of hours under which a field operation can be performed by tractor 3 using implement m, where m = 14, 15, 17, 18 and 35.

Labor Constraint:

$$X_{13}La_{13} + X_{14}La_{14} + X_{15}La_{15} + X_{16}La_{16} + X_{17}La_{17}$$
$$+ X_{18}La_{18} + X_{19}La_{19} + X_{20}La_{20} + X_{21}La_{21} + X_{22}La_{22}$$
$$+ X_{23}La_{23} + X_{24}La_{24} + X_{25}La_{25} + X_{26}La_{26} + X_{27}La_{27}$$
$$+ X_{28}La_{28} + X_{29}La_{29} + X_{30}La_{30} + X_{31}La_{31} + X_{32}La_{32}$$
$$+ X_{33}La_{33} + X_{34}La_{34} + X_{35}La_{35} + X_{39}La_{39} + X_{40}La_{40}$$
$$+ X_{41}La_{41} + X_{42}La_{42} - X_{44}La_{44} \leq 0 \qquad (4\text{-}20)$$

where:

X_n : Level of activity n (number of implements) where n = 13, . . . 35 and 39, . . . 44

La_m: Represents the number of hours required to accomplish a field operation for a land size of 200 ha, where m = 13, . . . 42 (the summary of the number of hours required for each implement to fulfill a field operation are presented in Table 4-1.

La_{44}: Is a vector of -1 which implies the summation of all of hours required for navy bean production for calculating the labor cost.

The initial results from the previous model indicated that planting Swan Valley variety in 70 cm row spacing and applying the direct harvesting method is the most profitable system at this stage that can be followed, but the numbers of field machinery selected by the model was fractional instead of integers which does not represent

TABLE 4-1

The Land Area that Can Be Covered by an Implement During Available Days and Time Required to Cover 200 Ha

Implement	Code	Number of Hectares*	Number of Hours**
Moldboard plow	M_1	155	174
Moldboard plow	M_2	187	145
Moldboard plow	M_3	217	124
Chisel plow	C_1	200	135
Chisel plow	C_2	255	105
Chisel plow	C_3	270	100
Fertlizer spreader	Z_1	209	116
Field cultivator	F_1	332	81
Field cultivator	F_2	393	66.6
Field cultivator	F_3	480	55.2
Field cultivator	F_4	579	43.2
Row planter	R_1	117	138
Row planter	R_2	174	91.7
Row planter	R_3	232	68.7
Row cultivator	V_1	165	164
Row cultivator	V_2	248	109
Row cultivator	V_3	330	82
Sprayer	S_1	100	120.5
Sprayer	S_2	135	200
Sprayer	S_3	200	135
Bean puller + windrower	B_1+W_1	113	170
Bean puller + windrower	B_2+W_2	169	113
Bean puller + windrower	B_3+W_3	225	85
Harvester	H_1	191	160
Harvester	H_2	239	128
Harvester (conventional)	H_3	209	92
Harvester (conventional)	H_4	262	73

*Number of hectares = [field capacity of an implement (ha/hr)] x number of hours available for field work (hr)]

**Number of hours = [land size (ha)] ÷ [field capacity of an implement (ha/hr)]

the terms of the real world. Therefore, a specific technique was followed to force the noninteger number of selected kinds of implements to be integers by adding the following constraints 4-1 through 4-38 where the equation number represents the row (constraint) number, and the subscripted x's value show the column (activity) number.

Forcing the tillage implements to be integers:

$$X_{15}Fr_{15} + X_{16}Fr_{16} + X_{17}Fr_{17} + X_{18}Fr_{18} = 1 \qquad (4\text{-}21)$$

where:

X_n : Level of activity n (number of tillage implements) where n = 15, . . . 18

Fr_m: A vector of ones for m = 15, . . . 18. These vectors of ones were set only under the tillage implements that can cover 200 ha or more during tillage time to guarantee the number of tillage implements to be integers.

$$X_{15}Fr_{15} \leq 1 \qquad (4\text{-}22)$$

$$X_{16}Fr_{16} \leq 1 \qquad (4\text{-}23)$$

$$X_{17}Fr_{17} \leq 1 \qquad (4\text{-}24)$$

$$X_{18}Fr_{18} \leq 1 \qquad (4\text{-}25)$$

Equations 21 to 25 were set to force the model to select just one integer kind of a tillage implement that can cover the 200 ha within the time limit.

Forcing the number of field cultivators to be integers:

$$X_{20}Fr_{20} + X_{21}Fr_{21} + X_{22}Fr_{22} + X_{23}Fr_{23} = 1 \qquad (4\text{-}26)$$

where:

X_n : Level of activity n (number of field cultivators) where n = 20, . . . 23

Fr_m: A vector of ones for m = 21, . . . 23. These vectors were set only under field cultivators which can cover 200 ha or more during cultivating time to guarantee the number of cultivators to be integers.

$$X_{20}Fr_{20} \leq 1 \qquad (4\text{-}27)$$

$$X_{21}Fr_{21} \leq 1 \qquad (4\text{-}28)$$

$$X_{22}Fr_{22} \leq 1 \qquad (4\text{-}29)$$

$$X_{23}Fr_{23} \leq 1 \qquad (4\text{-}30)$$

Equations 27 to 30 were set to force the model to select only one size of field cultivator.

Forcing the row planters to be integers:

$$X_{26}Fr_{26} = 1 \qquad (4\text{-}31)$$

Forcing the row cultivators to be integers:

$$X_{28}Fr_{28} + X_{29}Fr_{29} = 1 \qquad (4\text{-}32)$$

$$X_{28}Fr_{28} \leq 1 \qquad (4\text{-}33)$$

$$X_{29}Fr_{29} \leq 1 \qquad (4\text{-}34)$$

Forcing the sprayers to be integers:

$$X_{32}Fr_{32} = 1 \qquad (4\text{-}35)$$

Forcing the combine to be integers:

$$X_{40}Fr_{40} = 1 \qquad (4\text{-}36)$$

Forcing tractor 1 and tractor 2 to be integers:

$$X_{10}Fr_{10} = 1 \qquad (4\text{-}37)$$

(4-38)

4.2 Model Adjustments

The tractor usage in the farming process represents one of the most important factos affecting the total annual cost of crop production. In the MILP model the tractor usage was assumed to be 1000 hrs per year to estimate the annual cost of using Tractor 1, 2, and 3. However, the results obtained from the navy bean production model indicated that the actual number of hours for the tractor usage were as follows:

1. Utility tractor 1 (T_1 - 37.2 kw): 435 hours per year, 300 hrs of which were assumed to be used for handling transportation, making turns, etc., other than farming activities.
2. Tillage tractor 1 (T_2 - 59.7 kw): 442 hours per year, 100 hrs of which were assumed to be for non-farming activities (handling, transportation, turns, etc.)

3. Tillage tractor 3 (T_3 - 89.5 kw): 400 hours per year, 100 hrs of which were assumed to be for nonfarming activities.

These actual number of hours for tractor usage were fed in the machinery cost model by Rotz et al. (1981) to calculate the total cost for using Tractor 1, 2, and 3. The results obtained from the machinery cost model are summarized in Table 4.2.

4.3 Model Results

The navy bean production model results indicated that planting the Swan Valley variety in 70 cm row spacing and applying the direct harvesting method is the most profitable system that can be followed at this stage. A navy bean producer can make in this system up to $144,604.00 profit from 200 ha land which approximately equals $723.00 per ha. the summary of the navy bean production model results is presented in table 4-3. These results show the kinds and the sizes of implements selected by the model and represents the amount of seed, fertilizers and herbicides applied for Swan Valley planted in 200 ha land with 70 cm row spacing.

TABLE 4-2

Summary of the Adjusted Annual Cost
of Tractors 1, 2, 3 Over
Ten Year Period

Implement	Code	Ownership Cost	Repair & Maintenance	Fuel	Total Present Value	Average Annual Cost
Utility tractor	T1	8050	2786	17597	28434	3165
Tillage tractor	T2	12887	4576	28618	46081	5130
Tillage tractor	T3	14270	5832	38872	63929	7117

TABLE 4-3

Summary of the Final Solution of the
Navy Bean Production System

Items	Size	Final Solution
Land Size	200 ha	Swan Valley planted in 70 cm rows, applying direct harvesting method
Seeds		9000 kg
Fertlizer		54000 kg
Herbicide		1060 kg
Utility tractor	37.3 kw	1
Tillage tractor	59.7 kw	1
Chisel plow	2.4 m	1
Field cultivator	6.6 m	1
Row planter	6.0 m	1
Row cultivator	6.0 m	1
Sprayer	2.7 m	1
S.P. combine	5.0 m	1
Total yield		521 tonne
Hour requirement		604 hr
Total profit		$144,604.00
Total Profit per Hectare		723.00 $/ha

4.4 Sensitivity Analysis

Sensitivity analysis is the study of how the optimal solution and the value of the optimal solution to a linear programming change, given changes in the various coefficient of the variables in the model. There are several reasons why sensitivity analysis is considered so important from the managerial point of view. First of all, a farming system operates in a dynamic environment; cost of machines, labor, chemicals and crops change over time. Sensitivity analysis can also be used to determine how critical estimates of coefficients are in the solution to a linear programming. As another phase of sensitivity analysis, it is possible to calculate the cost of adding resources to relax the bending (limiting) constraints. Thus, the sensitivity analysis provides a good tool for additional valuable information for the decision maker.

4.4-1 Shadow Prices and Slacks

Shadow price is an economics term used to indicate the impact of increasing the right hand side for a linear programming constraint by one unit. In other words, it is the value of one additional unit of the resource associated with linear programming, while the slack variable represents the amount of unused resource. In the navy bean production model, those two variables were analyzed by the computer. The results of these analyses are summarized in Table 4-4.

These results indicate the following:

1. If the farmer is going to rent one more hectare of land he is willing to pay up to $847.00 per year otherwise it is not profitable to pay more than this value. This shadow price represents the value of the crop minus the operating cost for producing one ha of beans.
2. If the farmer is going to sell this crop, he is willing to accept .44 $/kg and up.
3. If the farmer is going to purchase one more kg of navy bean seeds, fertilizer and herbicides, he is willing to pay up to .88, .47 and 14.15 $/kg respectively.
4. If the farmer is going to plow one more hectare of land, he is willing to pay up to 10.68 $/ha to rent a plow.
5. By using the field cultivator F_4 (6.6 m), row planter R_3 (6.0 m), and the row cultivator V_3 (6.0 m). The farmer will have excess 379, 32, and 130 ha of land respectively. (Land can be covered in addition to 200 ha of land assumed t in the MILP model.)

TABLE 4-4

Summary of the Shadow Prices and the Slacks for the Navy Bean Production Model

Items	Unit	Shadow Price Value	Slack Value
Land	$/ha	847.87	
Yield	$/kg	.44	
Seed	$/kg	.88	
Fertilizer	$/kg	.47	
Herbicides	$/kg	14.15	
Plowing	$/ha	10.68	
Field cultivation	ha		376
Bean planting	ha		32
Row cultivation	ha		130
Spraying	$/ha	10.68	
Bean harvesting (directly)	ha		39
Using tractor 1	hr		865
Using tractor 2	hr		658
Using tractor 3	$/hr	7.11	
Labor	$/hr	6.00	

6. If the farmer is going to spray one more hectare of land, he is willing to pay up to 10.68 \$/ha to rent a sprayer.
7. By using harvester H_2 (5.0 m), the farmer will have excess 39 ha of land can be covered by this size of harvester.
8. By using tractor T_1 (37.3 kw) and tractor T_2 (59.7 kw), the farmer will have excess 865, and 658 hours per year respectively to cover 1000 hours per year for each tractor.
9. If the farmer is going to rent a tractor T_3 (89.5 kw), he is willing to pay up to 15.76 \$/hr to use the tractor.
10. If the farmer is going to use additional employees to fulfill the field work, he is willing to pay 6.0 dollars per hour for each employee.

4.4-2 The Cost of Forcing Nonoptimal Activities Into the Optimal Solution

It is a measure of the economic impacts of forcing in nonoptimal activities into the final solution. The results obtained from the computer analysis are shown as follows:

1. Planting Fleetwood in 35 cm row spacing using the direct harvest method instead of planting Swan Valley in 70 cm rows using the direct harvest method would cost the farmer $690.89 for each hectare of land.
2. Planting Fleetwood in 70 cm row spacing and applying the direct harvest method would cost a farmer $415.80 more for each hectare of land compared to planting Swan Valley in 70 cm rows and applying the direct harvest method.
3. Planting Fleetwood in 70 cm rows and applying the conventional harvest method, would cost the farmer $365.48 more for each hectare of land compared to planting Swan Valley in the optimal solution.
4. Planting Swan Valley in the narrow row system (35 cm) and applying the direct harvest method would cost a navy bean producer $392.57 more for each hectare of land compared to planting Swan Valley in 70 cm rows.
5. Planting Swan Valley in 70 cm rows and harvesting conventionally would cost the farmer $314.88 more for each hectare of land compared to the direct harvest method.
6. Forcing moldboard plow 1 (M_1--2.0m) or moldboard plow 2 (M_2--2.4m) or moldboard plow 3 (M_3--2.8m) into plowing operation would cost $1145.93, $1859.94 and $1322.78 per year, respectively.

7. Forcing field cultivator (F_1--3.8m) would cost \$31.00 per year.
8. Using row planter 1 (R_1--3.0m) or row planter 2 (R_2--4.5m), would add \$2,003.00 and \$1,903.00 per year, respectively to the total costs.
9. Using harvester 1 (H_1--4 rows) instead of harvester 2 (H_2--5 rows) would add \$11,075.00 per year to the total cost.

It should be noted from these results that forcing an implement into the final solution would also force the corresponding tractor (T_1, T_2, or T_3) to be in the final solution. This would result in some additional cost attributed to the cost of using a tractor in the total annual cost of an operation.

4.4-3 Range of Optimality

The range of optimality is defined as the range of values over which the objective function coefficient for a variable may change without changing the optimal solution. The results obtained from the computer analysis indicated the following:

1. Planting Swan Valley variety in 70 cm rows and applying the direct harvest method would still hold in the optimal solution as long as the

insecticides and fungicides cost per hectare does not exceed $385.00

2. The optimal solution can hold as long as the Swan Valley seed price is less than $9.25 per kilogram.
3. The fertilizer price can go up to $3.26 per kg without affecting the optimal solution for the model.
4. The optimal solution can be held as long as the herbicide market price is below $156.54 per kg.
5. Using tractor 1 (T_1--37.3 kw), tractor 2 (T_2--59.7 kw), or tractor 3 (T_3--89.5 kw) in the farming process depends on the corresponding equipment that can be matched with a tractor.
6. Using the chisel plow 1 (C_1--2.4m) would still be in the optimal solution as long as the total annual cost is $1,446.00 or lower and as long as tractor 2 (T_2--59.7 kw) is the most profitable. This situation may change if tractor 2 is no longer in the optimal solution.
7. Using the field cultivator 4 (F_4--6.6m) would no longer be in the optimal solution if the cost of use exceeds $826.00. In this case field cultivator 2 (F_2--4.7m) would be the candidate for replacing field cultivator 4.

8. Using row planter 3 (R_3--6.0m) would be in the optimal solution as long as the annual cost for the planter does not exceed $2,464.00 per year. Otherwise planter 2 (R_2--4.5m) would be the competitive machine that might replace it.
9. Using the row cultivator 3 (V_3--6.0m) would be in the optimal solution as long as the annual cost for that implement does not exceed $804.00. Otherwise row cultivator 2 (V_2--4.5m) would be the candidate to replace row cultivator 3.
10. Using sprayer 3 (S_3--2.77m) would no longer be in the optimal solution if the annual cost of use exceeds $1,177.00. In this case sprayer 2 (S_2--1.86m) would be the competitor to replace sprayer 3.
11. The use of harvester 2 (H_2--5.0m) would be in the optimal solution as long as the total annual cost of using this harvester is below $13,669.00. Otherwise harvester 1 (H_1--4.0m) would be the alternative choice.
12. This optimal solution can be held as long as the navy bean market price is $.15 per kg and up.

5 NAVY BEAN-CORN PRODUCTION MODEL

5.1 Model Formulation

Crop selection, machinery selection, and field work scheduling are interrelated and require an integrated planning process that can evaluate simultaneously the effects of machinery purchase and crop production alternatives within the resource constraints imposed on a farm.

A mixed integer linear programming model was formulated with 45 columns (activities) and 39 rows (constraints) to accomplish the following:

Evaluate and compare navy bean (specifically, Swan Valley variety planted in 70 cm and harvested directly which give the best results in the navy bean production model), and corn production in Michigan. This algorithm was developed to find:

1. Which crop was more beneficial to the farmers.
2. What profit could be made under different land percentages of navy bean and corn
3. What machinery set to contribute to a selected crop production system.

The following equations described the MILP model structure:

<u>The objective function</u>:

$$\begin{aligned}\text{Maximize } z = & -X_1Be - X_2CO - X_3SB - X_4FB - X_5HB - X_6SC \\ & -X_7FC - X_8HC - X_9T_1 - X_{10}T_2 - X_{11}T_3 \\ & -X_{12}C_1 - X_{13}C_2 - X_{14}C_3 - X_{15}FB_2 - X_{16}FB_3 \\ & -X_{17}FB_4 - X_{18}FC_2 - X_{19}FC_3 - X_{20}FC_4 \\ & -X_{21}RB_1 - X_{22}RB_2 - X_{23}RB_3 - X_{24}RC_1 \\ & -X_{25}RC_2 - X_{26}RC_3 - X_{27}VB_1 - X_{28}VB_2 \\ & -X_{29}VB_3 - X_{30}VC_1 - X_{31}VC_2 - X_{32}VC_3 \\ & -X_{33}SB_1 - X_{34}SB_2 - X_{35}SB_3 - X_{36}SC_1 \\ & -X_{37}SC_2 - X_{38}SC_3 - X_{39}HB_1 - X_{40}HB_2 \\ & -X_{41}HC_1 - X_{42}HC_2 - X_{43}SB - X_{44}SC - X_{45}LA\end{aligned}$$

where:

Z : The total net profit \$/yr

X_n : Level of activity n, where n = 1 . . . . 45 and it indicates the column number.

CO : Insecticide and fungicide cost (\$/ha) for corn production.

SB, SC : Seed prices (\$/kg) for navy beans and corn, respectively.

FB, FC : Fertilizer costs (\$/kg) for beans and corn, respectively.

HB, HC : Herbicide costs (\$/kg) for beans and corn, respectively.

Table 3-9 represents the summary of corn production data used in the navy bean-corn model:

Tm : Annual costs of using tractor m (\$/year) where m = 1,2,3,.

CM : Annual cost of using chisel plow m (\$/year) where m = 1,2,3.

FB_m, FC_m : Annual costs of using field cultivator m (\$/year) for bean and corn production, respectively, where m = 2,3,4.

RB_m, RC_m : Annual costs of using row planter m (\$/year) for planting beans and corn, respectively, where m = 1,2,3.

VB_m, VC_m : Annual costs of using row cultivator m (\$/year) for cultivating beans and corn, respectively, where m = 1,2,3.

SB_m, SC_m : Annual costs of using field sprayer m (\$/year) for spraying beans and corn, respectively, where m = 1,2,3.

HB_m, HC_m : Annual costs of using harvester m (\$/year) for harvesting beans and corn, respectively, where m = 1,2.

SB : Market sale price of navy beans (\$/kg).

SC : Market sale price of corn (\$/bu).

LA : Labor cost per hour (\$/hr, assumed to be \$6/hr).

Table 3-8 summarizes the total annual costs for each implement used in the navy bean-corn production model.

The objective function was maximized subject to a series of constraints illustrated by equations (5-1) through (5-39), where the equation number represents the row number (constraint number), and the subscripted X's indicate the column number (activity number).

<u>Land constraints</u>:

$$X_1a_1 + X_2a_2 \leq b_1 \qquad (5\text{-}1)$$

where:

X_n : Level of activity n (land area in ha) where n = 1,2.

a_n : Is a vector (value) matrix of ones for bean and corn production where n = 1,2.

b_1 : Is a land area limitation (it was set to be 200 ha).

<u>Yield constraints</u>:

$$-X_1Y_1 + X_{43}Y_{43} \leq 0 \qquad (5\text{-}2)$$

$$-X_2Y_2 + X_{44}Y_{44} \leq 0 \qquad (5\text{-}3)$$

where:

X_n : Is the level of activity n (size of land in ha) where n = 1,43 in the first equation and 2,44 in the second.

Y_1 : Represents the navy bean yield level (kg/ha).

Y_{43} : A vector of 1 under selling bean activity.

Y_2 : The corn yield level (bu/ha).

Y_{44} : A vector of 1 under selling corn activity.

Seeding rate constraints:

$$X_1Se_1 - X_3Se_3 \leq 0 \qquad (5\text{-}4)$$

$$X_2Se_2 - X_6Se_6 \leq 0 \qquad (5\text{-}5)$$

where:

X_n : Level of activity n (size of land), where n = 1,3 and 2,6.

Se_1 : Amount of required navy bean seed (kg/ha).

Se_3 : A vector of -1 under navy bean seed price ($/kg)

Se_2 : Amount of corn seed required (kg/ha).

Se_6 : A vector of -1 under corn seed price ($/kg).

Fertilizer rate constraints:

$$X_1Fe_1 - X_4Fe_4 \leq 0 \qquad (5\text{-}6)$$

$$X_2Fe_2 - X_7Fe_7 \leq 0 \qquad (5\text{-}7)$$

where:

X_n : Level of activity n (size of land), where n = 1,4 and 2,7.

Fe_1 : Amount of fertilizer required for bean production (kg/ha).

Fe_4 : A vector of -1 under fertilizer market price ($/kg).

Fe_2 : Amount of fertilizer required for corn production (kg/ha).

Fe_7 : A vector of -1 under fertilizer market price ($/kg).

Herbicides rate constraints:

$$X_1He_1 - X_5He_5 \leq 0 \tag{5-8}$$

$$H_2He_2 - X_8He_8 \leq 0 \tag{5-9}$$

where:

X_n : Level of activity n (size of land), where n = 1,5 and 2,8.

He_1 : Amount of herbicide required for bean production (kg/ha).

He_5 : A vector of -1 under the herbicide market price ($/kg).

He_2 : Amount of herbicide required for corn production (kg/ha).

He_8 : A vector of -1 under the herbicide market price ($/kg).

Plowing operation:

$$X_1PO_1 + X_2PO_2 - X_{12}PO_{12} - X_{13}PO_{13}$$

$$-X_{14}PO_{14} \leq 0 \tag{5-10}$$

where:

X_n : Level of activity n (number of tillage implements) , where n = 1,2,12,13,14.

PO_m : Is a vector of ones under bean and corn production where m = 1,2.

PO_k : Is a vector of the number of hectares chisel plow k can cover during plowing time where k = 12,13,14.

Field cultivation:

$$X_1Ha_1 - X_{15}Ha_{15} - X_{16}Ha_{16} - X_{17}Ha_{17} \leq 0 \tag{5-11}$$

where:

X_n : Level of activity n (number of field cultivators), where n = 1,15,16,17

Ha_1 : A vector of 1 under bean proudction

Ha_m : Is a matrix of number of hectares that field cultivator m can cover during the cultivating time where m = 15, . . .17

$$X_2Ha_2 - X_{18}Ha_{18} - X_{19}Ha_{19} - X_{20}Ha_{20} \leq 0 \qquad (5\text{-}12)$$

where:

X_n : Level of activity n (number of field cultivators), where n = 1,18,19,20

Ha2 : A vector of 1 under corn production

Ham : Is a matrix of number of hectares that field cultivator m can cover during cultivating time where m - 18, . . . 20

<u>Planting operation</u>:

$$X_1pL_1 - X_{21}pL_{21} - X_{22}pL_{22} - X_{23}pL_{23} \leq 0 \qquad (5\text{-}13)$$

where:

X_n : Level of activity n (number of row planters), where n = 1,21,22,23.

pL_1 : A vector of 1 under bean production.

pL_m : Represents the number of hectares that row planter m can cover during planting time where m = 21, . . . 23.

$$X_2pL_2 - X_{24}pL_{24} - X_{25}pL_{25} - X_{26}pL_{26} \leq 0 \qquad (5\text{-}14)$$

where:

X_n : Level of activity n, where n = 1,24,25,26.

pL_2 : A vector of 1 under corn production.

pL_m : Represents the number of hectares that row planter m can cover during corn planting time where m = 24, . . . 26.

Row cultivator:

$$X_1Cu_1 - X_{27}Cu_{27} - X_{28}Cu_{28} - X_{29}Cu_{29} \leq 0 \qquad (5\text{-}15)$$

$$X_2Cu_2 - X_{30}Cu_{30} - X_{31}Cu_{31} - x_{32}Cu_{32} \leq 0 \qquad (5\text{-}16)$$

where:

X_n : Level of activity n (number of row cultivators), where n = 1,27 . . . 29 and 2,30 . . . 32.

Cu_1Cu_2 : A vector of 1 under bean and corn production, respectively.

Cu_m : A vector of the number of hectares that row cultivator m can accomplish during cultivating time in a bean field, where m = 27 . . . 29 (F_2,F_3,F_4).

Cu_k : A vector of the number of hectares that row cultivator k can perform during cultivating time in a corn field, where k = 30 . . . 32 (F_2,F_3,F_4).

Spraying operation:

$$X_1Sp_1 - X_{33}Sp_{33} - X_{34}Sp_{34} - X_{35}Sp_{35} \leq 0 \qquad (5\text{-}17)$$

$$X_2Sp_2 - X_{36}Sp_{36} - X_{37}Sp_{37} - X_{38}Sp_{38} \leq 0 \qquad (5\text{-}18)$$

where:

X_n : Level of activity n (number of sprayers), where n = 1,33 . . . 35 and 2,36 . . . 38.

Sp_1, Sp_2 : A vector of 1 under bean and corn production, respectively.

Sp_m : Number of hectares that field sprayer m can cover during spraying time in a bean field, where m = 33, ... 35 (S_1,S_2,S_3).

Sp_k : Number of hectares that field sprayer k can perform during spraying time in a corn field, where k = 36, . . . 38 (S_1,S_2,S_3).

Harvesting operation:

$$X_1hr_1 - X_{39}hr_{39} - X_{40}hr_{40} \leq 0 \qquad (5\text{-}19)$$

$$X_2hr_2 - X_{41}hr_{41} - X_{42}hr_{42} \leq 0 \qquad (5\text{-}20)$$

where:

X_n : Level of activity n (number of harvesters), where n = 1,39,40 and 2,41,42.

hr_1, hr_2 : A vector of 1 under bean and corn production, respectively.

hr_m : Number of hectares that harvester m can accomplish during bean harvesting time, where m = 39,40 (H_1,H_2).

hr_k : Number of hectares that corn harvester k can cover during corn harvesting time, where k = 41,42 (H_5,H_6).

The results obtained about the number of hectares an implement can cover within the time limit are shown in Table 5-1. It should be noted that the same implements used for executing field operations for navy bean production were used for corn production but under different sequence numbers. This technique was used to distinguish between bean field operations and corn field operations because some field operations for bean and corn production may have different time limits to accomplish the field work, which could result in different sizes of implements to be selected by the model.

Usage of tractor 1:

$$- X_9Ta_9 + X_{15}Ta_{15} + X_{18}Ta_{18} + X_{21}Ta_{21} + X_{24}Ta_{24} + X_{27}Ta_{27} + X_{28}Ta_{28} + X_{30}Ta_{30} + X_{31}Ta_{31} + X_{33}Ta_{33} + X_{34}Ta_{34} + X_{35}Ta_{35} + X_{36}Ta_{36} + X_{37}Ta_{37} + X_{38}Ta_{38} \leq 0 \qquad (5\text{-}21)$$

where:

X_n : Level of activity n (number of implements)

u Ta_9 : Recommended number of hours for tractor 1 to be used for executing field operation (it was assumed to be 1,000 hrs).

TABLE 5-1

The Land Area that can be Covered by an Implement During the Available Workable Days and the Time Required to Cover 200 Ha

Implement	Code	Number of Hectares*	Number of Hours**
Chisel plow	C_1	200	135
Chisel plow	C_2	255	105
Chisel plow	C_3	270	100
Field cultivator	F_2	295	66.6
Field cultivator	F_3	360	55.5
Field cultivator	F_4	432	43.2
Row planter	R_1	117	139
Row planter	R_2	174	91.7
Row planter	R_3	232	68.7
Row cultivator	V_1	176	164
Row cultivator	V_2	263	109
Row cultivator	V_3	351	82
Sprayer	S_1	120	274
Sprayer	S_2	160	200
Sprayer	S_3	236	135
Corn harvester	H_5	191	160
Corn harvester	H_6	239	128

*Number of hectares = [field capacity of an implement (ha/hr)] x number of hours available for field work (hr)]

**Number of hours = [land size (ha)] ÷ [field capacity of an implement (ha/hr)]

Ta_m : Number of hours under which each field operation can be performed by tractor 1 using implement m where m = 15,18,21,24, 27,28,30,31,33,34,35,36,37,38 [the number of hours under which a field operation can be performed were calculated by dividing the land area (200 ha was assumed in this model) by the implement capacity (ha/hr)].

<u>Usage of tractor 2</u>:

$$- X_{10}Ta_{10} + X_{12}Ta_{12} + X_{16}Ta_{16} + X_{17}Ta_{17} + X_{19}Ta_{19} + X_{20}Ta_{20} + X_{22}Ta_{22} + X_{23}Ta_{23} + X_{25}Ta_{25} + X_{26}Ta_{26} + X_{29}Ta_{29} + X_{32}Ta_{32} \leq 0 \qquad (5\text{-}22)$$

where:

X_n : Level of activity n (number of implements)

Ta_{10} : Recommended number of hours for tractor 2 to be used for executing field operation (the number of hours was assumed to be 1,000 hrs).

Ta_m : Number of hours under which a field operation can be fulfilled by tractor 2 using implement m, where m = 12,16,17,19,20,22,23,25,26,29 and 32.

Usage of Tractor 3:

$$- X_{11}Ta_{11} + X_{13}Ta_{13} + X_{14}Ta_{14} \leq 0 \qquad (5\text{-}23)$$

where:

X_n : Level of activity n (number of implements)

Ta_{11} : Recommended number of hours for tractor 3 to be used for executing field operation (the recommended number of hours were set to be 1,000 hrs).

Ta_m : Number of hours under which a field operation can be accomlished by tractor 3 using implement m, where m = 13,14.

Labor constraints:

$$\begin{aligned}
&X_{12}La_{12} + X_{13}La_{13} + X_{14}La_{14} + X_{15}La_{15} + X_{16}La_{16} \\
&+ X_{17}La_{17} + X_{18}La_{18} + X_{19}La_{19} + X_{20}La_{20} + X_{21}La_{21} \\
&+ X_{22}La_{22} + X_{23}La_{23} + X_{24}La_{24} + X_{25}La_{25} + X_{26}La_{26} \\
&+ X_{27}La_{27} + X_{28}La_{28} + X_{29}La_{29} + X_{30}La_{30} + X_{31}La_{31} \\
&+ X_{32}La_{32} + X_{33}La_{33} + X_{34}La_{34} + X_{35}La_{35} + X_{36}La_{36} \\
&+ X_{37}La_{37} + X_{38}La_{38} + X_{39}La_{39} + X_{40}La_{40} + X_{41}La_{41} \\
&+ X_{42}La_{42} - X_{45}La_{45} \leq 0 \qquad (5\text{-}24)
\end{aligned}$$

where:

X_n : Level of activity n (number of implements), where n = 12, . . . 42 and 45.

La_m : Represents the number of hours required to accomplish a field operation for a land size of 200 ha, where m = 12, . . . 42 (the summary of the numbers of hours required for each implement to fulfill a field operation were shown in Table 4-1.

La_{45} : Is a vector of -1 which implies the summation of all number of hours required for navy bean and corn production for calculating the labor cost.

The number of hours required for each implement to accomplish field work was presented in Table 5-1.

The initial result obtained from this model indicated that planting navy beans is more profitable to farmers than planting corn. However, the number of implements selected by the model were fractional numbers rather than integers which is not feasible. Therefore, some constraints were added to the model to force the previously selected implements to be integers. These constraints are listed as follows:

<u>Forcing the number of chisel plows to be an integer</u>:

$$X_{12}Fr_{12} + X_{13}Fr_{13} + X_{14}Fr_{14} = 1 \qquad (5\text{-}25)$$

$$X_{12}Fr_1^2 \leq 1 \qquad (5\text{-}26)$$

$$X_{13}Fr_{13} \leq 1 \qquad (5\text{-}27)$$

$$X_{14}Fr_{14} \leq 1 \qquad (5\text{-}28)$$

where:

X_n : Level of activity n (number of chisel plows).

Fr_m : A vector of ones for m = 12,13,14. These vectors of ones were set only under the size of chisel plow that can cover 200 ha or more within the time limit to guarantee that the number of tillage implements be integers.

<u>Forcing the number of field cultivators to be an integer</u>:

$$X_{15}Fr_{15} + X_{16}Fr_{16} + X_{17}Fr_{17} = 1 \qquad (5\text{-}29)$$

$$X_{15}Fr_{15} \leq 1 \qquad (5\text{-}30)$$

$$X_{16}Fr_{16} \leq 1 \qquad (5\text{-}31)$$

$$X_{17}Fr_{17} \leq 1 \qquad (5\text{-}32)$$

where:

X_n : Level of activity n (number of field cultivators).

Fr_m : A vector of ones for m = 15,16,17 (F_2,F_3,F_4).

<u>Forcing the number of row planters to be an integer</u>:

$$X_{23}Fr_{23} = 1 \qquad (5\text{-}33)$$

where:

X_{23} : Level of activity (number of row planters).

Fr_{23} : A vector of 1 under only row planter 3 that can cover 200 ha within the time limit.

Forcing the number of row cultivators to be an integer:

$$X_{28}Fr_{28} + X_{29}Fr_{29} = 1 \quad (5\text{-}34)$$

$$X_{28}Fr_{28} \leq 1 \quad (5\text{-}35)$$

$$X_{29}Fr_{29} \leq 1 \quad (5\text{-}36)$$

where:

X_n : Level of activity n (number of row cultivators).

Fr_m : A vector of ones under row cultivators number 2 and 3 because they are capable of cultivating 200 ha or more within the time limit.

Forcing the number of harvesters to be an integer:

$$X_{42}Fr_{42} = 1 \quad (5\text{-}37)$$

where:

X_{42} : Level of activity n (number of harvesters).

Fr_m : A vector of 1 under harvester number 2 which is capable of harvesting 200 ha within the time limit.

Forcing the number of tractors to be an integer:

$$X_9Fr_9 = 1 \quad (5\text{-}38)$$

$$X_{10}Fr_{10} = 1 \quad (5\text{-}39)$$

where:

X_n : Level of activity n (number of tractors).

Fr_m : A vector of 1 under utility tractor 1 and tillage tractor 2.

5.2 Model Adjustments

In the MILP model the tractor usage was assumed to be 1000 hours per year which in fact does not represent the real world system. However, the results obtained from the navy bean-corn production model indicated that the actual number of hours for utility tractor 1 (T_1 - 37.3 kw) usages was 435 hours per year, 300 hours of which were assumed to be used for nonfarming activities (handling, transportation, turns, etc.). While the number of hours for using tillage tractor 2 (T_2 - 59.7 kw) and tillage tractor 3 (T_3 - 89.5 kw) were found to be 442 and 400 hours, respectively. Therefore, the total annual cost of using tractor 1, 2, and 3 were recalculated using machinery cost model by Rotz et al. (1981). The results of these calculations are presented in Table 4-2. The new annual costs of using tractor 1, 2, and 3 were then fed into the MILP model to calculate the net profit for the navy bean-corn production model which intended to select the most profitable crop can be produced with respect to the agronomic and machinery requirements.

5.3 Model Results

The results obtained from navy bean-corn production model indicated that under present corn yield level (6037.00 kg/ha) and market price (0.93 $/kg), navy bean production is more profitable than corn. A navy bean producer can realize up to $135,801.00 in profit from a 200-ha farm which equals approximately $680.00 per ha. A summary of the navy bean-corn production model results is presented in Table 5-2. These results illustrate the amount of seed, fertilizer, and herbicides required for the Swan Valley variety planted in 200 ha and represent the type and size of implements selected by the model.

5.4 Sensitivity Analysis

5.4-1 Shadow Prices and Slacks

Shadow price is an economics term used to indicate the impact of increasing the right-hand side for a linear programming constraint by one unit. The slack variable represents the amount of unused resource. The results of shadow prices and slack variables were presented in Table 4-3.

TABLE 5-2

Summary of the Final Solution of the
Navy Bean-Corn Production Model

Items	Size	Final Solution
Land Size	200 ha	Navy Bean
Agronomic Requirements		
Seeds		9000 kg
Fertilizer		54000 kg
Herbicide		1060 kg
Machinery Requirements		
Utility tractor	37.3 kw	1
Tillage tractor	59.7 kw	1
Chisel plow	2.4 m	1
Field cultivator	6.6 m	1
Row planter	6.0 m	1
Row cultivator	6.0 m	1
Sprayer	2.7 m	1
S.P. combine	5.0 m	1
Labor Requirements		604 hr
Total yield		521 tonne
Total profit		$144604.00
Net profit per ha		723.00 $/ha

5.4-2 The Cost of Forcing in Nonoptimal Solution

The cost of forcing in nonoptimal solution is an economics term used to indicate the impact of forcing nonoptimal activities into final solution. The results obtained from the computer analysis indicated the following:

1. Planting corn instead of navy beans, would cost the farmer $582.00 more for each hectare of land.
2. Forcing field cultivators (F_1--3.8m) into the optimal solution would add $31.00 to the total annual cost.
3. Using row planter 1 (R_1--3.0m) or row planter 2 (R_2--4.5m) instead of row planter 3 (R_3--6.0m) would increase the total annual cost by $2,003.00 and $1,903.00, respectively.
4. Using row cultivator 1 (V_1--3.0m) instead of row cultivator (V3--6.0m) would add $1466.00 to the total annual cost.
5. Forcing sprayer 1 (S_1--1.4m) or sprayer 2 (S_2--1.86m) instead of sprayer 3 (S_3--2.7m) into the optimal solution would add $1,416.00 and $772.00 per year, respectively.

6. Using harvester 1 (H_1--4m) instead of harvester 2 (H_2--5m), would add $11,075.00 per year to the total annual cost.

It should be noted from these results that forcing an implement into the final solution would also force the corresponding tractor (T_1, T_2, or T_3) to be in the final solution. This would result in some additional cost attributed to the cost of using a tractor in the total annual cost of an operation.

5.4-3 Range of Optimality

The range of optimality indicates the range of values over which the objective function coefficient for a variable may change without changing the optimal solution. The results obtained from the computer analysis indicatd the following.

1. Planting Swan Valley variety in 70 cm rows and applying the direct havesting method would still hold in the optimal solution as long as the insecticide and fungicide costs per hectare do not exceed $560.00
2. The optimal solution can be held as long as the Swan Valley seed price is less than $12.45 per kilogram.

3. The fertilizer price can go up to \$2.39 per kg without affecting the optimal solution for the model.
4. The optimal solution will hold as long as the herbicide market price is below \$112.40 per kg.
5. Using tractor 1 (T_1--37.7 kw), or tractor 2 (T_2--59.7 kw), or tractor 3 (T_3--89.5 kw) in the farming process depends upon the corresponding equipment that can be matched with a tractor.
6. Using chisel plow 1 (C_1--2.4m) would no longer be in the optimal solution if the cost of use exceeds \$1,446.00 per year and as long as tractor 2 (T_2--59.7 kw) is in the optimal solution.
7. The use of field cultivator 4 (F_4--6.6m) would still be in the optimal solution as long as the total annual cost was \$906.13 and lower. Otherwise, field cultivator 3 (F_3--5.6m) would be the candidate for replacing field cultivator 4.
8. The use of row planter (R_3--6.0m) would be in the optimal solution as long as the annual cost for the planter does not exceed \$2,689.00. Otherwise, row planter 2 (R_2--4.5m) would be the competitve machine to replace it.

9. The use of row cultivator 3 (V_3--6.0m) would be in the optimal solution as long as the annual cost for the cultivator does not exceed $1,244.40. Otherwise, row cultivator 2 (V_2--4.5m) would be the candidate for replacing row cultivator 3.
10. The use of sprayer 3 (S_3--2.77m) would no longer be in the optimal solution if the annual cost of use exceeds $2,607.00. Otherwise, sprayer 2 (S_2--1.86m) would be the competitive for replacing sprayer 3.
11. The use of harvester 2 (H_2--5m) would still be in the optimal solution as long as the total annual cost of using the harvester is below $13,090.24. Otherwise, harvester 1 (H_1--4m) would be the alternative machine.
12. This optimal solution can be held as long as the navy bean market price is higher than $.24 per kilogram and the corn market price is less than $4.92 per bushel.

5.5 Testing Different Percentages of Bean and Corn in the Navy Bean-Corn Production Model

5.5-1 A 75 Percent Bean-25 Percent Corn Production System

In order to study the economic impacts of having a system of 75 percent beans and 25 percent corn (150 ha beans and 50 ha corn) on the farmer's profit, some changes took place in the previous navy bean-corn model. It is obvious that although the same field operations had to be accomplished with the same implements for both navy beans and corn, the execution time and the time limit are different for some of these field operations. Therefore, constraints number 25 to 37 were substituted from the previous model with the following constraints to satisfy the new condition and to have integer number of implements.

Forcing the navy bean land size to be 150 ha:

$$X_1 Fr_1 = 150 \qquad (5\text{-}25)$$

where:

X_1 : Is a level of activity 1 (size of land for planting bean).

Fr_1 : A vector of 1 under navy bean activity in order to force the navy bean land size to be 150 ha.

Forcing the number of chisel plows to be an integer:

$$X_{12}Fr_{12} + X_{13}Fr_{13} + X_{14}Fr_{14} = 1 \qquad (5\text{-}26)$$

$$X_{12}Fr_{12} \leq 1 \qquad (5\text{-}27)$$

$$X_{13}Fr_{13}$$

$$X_{14}Fr_{14} \leq 1 \qquad (5\text{-}29)$$

where:

X_n : Level of activity n (number of chisel plow).

Fr_m : A vector of 1 under chisel plow 1, 2 and 3. It should be noted that these vectors of ones were set under the size of chisel plow that can cover 200 ha, since the plowing time for both crops can be accomplished at the same time of the year.

Forcing the number of field cultivators to be an integer:

$$X_{15}Fr_{15} + X_{18}Fr_{18} = 1 \qquad (5\text{-}30)$$

where:

X_n : Level of activity n (number of field cultivators).

Fr_m : A vector of 1 under field cultivator 2 (F_2--4.7m). It should be noted that the same field cultivator (F_2--4.7m) was used to cultivate the bean land and the corn land, because the execution time is different and F_2 is capable of covering the land size for each crop within the time limit.

Forcing the number of row planters to be an integer:

$$X_{22}Fr_{22} + X_{25}Fr_{25} = 1 \qquad (5\text{-}31)$$

where:

X_n : Level of activity n (number of row planters).

Fr_m : A vector of 1 under row planter 2 (R_2--4.5m). It should be noted that although the row planter existed under columns 22 and 25, these columns refer to the same row planter (R_2--4.5m) because the planting operation is performed at different times for beans and corn.

Forcing the number of row cultivators to be integers:

$$X_{27}Fr_{27} + X_{30}Fr_{30} = 1 \qquad (5\text{-}32)$$

where:

X_n : Level of activity n (number of row cultivators).

Fr_m : A vector of 1 under row cultivator 1 (V_1--3m). This row cultivator existed under two columns because of the same previous reasons.

Forcing the number of sprayers to be an integer:

$$X_{35}Fr_{35} + X_{38}Fr_{38} = 1 \qquad (5\text{-}33)$$

where:

X_n : Level of activity n (number of sprayers).

Fr_m : A vector of 1 under sprayer 3 (S_3--2.7m).

<u>Forcing the number of harvesters to be an integer</u>:

$$X_{39}Fr_{39} + X_{41}Fr_{41} = 1 \qquad (5\text{-}34)$$

where:

X_n : Level of activity n (number of harvesters).

Fr_m : A vector of 1 under harvester (H_1--4m). It should be noted that the same harvester was used to harvest beans and corn but from different headers.

<u>Forcing tractor 1 and 2 to be an integer</u>:

$$X_9Fr_9 = 1 \qquad (5\text{-}35)$$

$$X_{10}Fr_{10} = 1 \qquad (5\text{-}36)$$

where:

X_n : Level of activity n (number of tractors).

Fr_m : A vector of 1 under tractor (T_1--37.3 kw) and tractor 2 (T_2--59.7 kw).

5.5-2 Model Adjustment

It was found from the previous model adjustment results that the total net profit tended to jump up 6.5 percent by involving the actual number of hours rather than 1000 hours for tractor usage. Therefore, in the following navy bean-corn production systems, a correction term of 6.5 percent were added to the total net profit for each system to obtain a more realistic figure for the profit.

5.5-3 Model Results

The results from this model indicated that a farmer can make up to $119,622.00 per year if 150 ha of land is planted with beans and 50 ha is planted with corn, which equals approximately $598.00 per hectare. The final results of this model are presented in Table 5-3 and shown in Figure 5-1.

5.5-4 A 50 Percent Bean-50 Percent Corn Production System

In order to study the economic impact of having a farm with 50 percent beans and 50 percent corn (a land of 100 ha beans and 100 ha corn was assumed in this model) on the farmer's profit, some changes were made in the main navy bean-corn model. These changes were included, deleting constraints number 25 to 39 and adding instead the following constraints to satisfy the new production conditions.

<u>Forcing the size of land to be 100 ha beans and 100 ha corn:</u>

$$X_1Fr_1 = 100 \qquad (5\text{-}25)$$

TABLE 5-3

Summary of the Final Solution of the
75 Percent Navy Bean - 25 Percent
Corn Production Model

Items	Size	Final Solution
Land	150 ha	Navy Bean
Land	50 ha	Corn
Bean Agronomic Requirements		
Seeds		6750 kg
Fertilizer		40500 kg
Herbicide		795 kg
Corn Agronomic Requirements		
Seeds		700 kg
Fertilizer		15500 kg
Herbicide		170 kg
Machinery Requirements		
Utility tractor	37.3 kw	1
Tillage tractor	59.7 kw	1
Chisel plow	2.4 m	1
Field cultivator	4.7 m	1
Row planter	4.5 m	1
Row cultivator	3.0 m	1
Sprayer	2.7 m	1
S.P. combine	4.0 m	1
Labor Requirements		766.7 hr
Total bean yield		390.75 tonne
Total corn yield		301.88 tonne
Total profit		$119662.00
Net profit per ha		598.00 $/ha

where:

X_1 : Level of activity 1 (planting navy beans).

Fr_1 : A vector of 1 under navy bean production.

<u>Forcing the number of chisel plows to be an integer</u>:

$$X_{12}Fr_{12} + X_{13}Fr_{13} + X_{14}Fr_{14} = 1 \qquad (5\text{-}26)$$

$$X_{12} \leq 1 \qquad (5\text{-}27)$$

$$X_{13}Fr_{13} \leq 1 \qquad (5\text{-}28)$$

$$X_{14}Fr_{14} \leq 1 \qquad (5\text{-}29)$$

where:

X_n : Level of activity n (number of chisel plows).

Fr_m : A vector of ones under chisel plow 1, 2, and 3. It should be noted that these vectors of ones were set under the size of chisel plow that can cover 200 ha since the plowing operation time for both crops can be accomplished at the same time of the year.

<u>Forcing the number of field cultivators to be an integer</u>:

$$X_{15}Fr_{15} + X_{18}Fr_{18} = 1 \qquad (5\text{-}30)$$

where:

X_n : Level of activity n (number of field cultivators).

Fr_m : A vector of ones under field cultivator 2 (Fr_2--4.7m).

It should be noted that the same field cultivator was used to cultivate the bean land and the corn land, because the cultivation is executed at different times and cultivator F_2 is capable of covering the land size for each crop within the time limit.

<u>Forcing the number of row planters to be an integer</u>:

$$X_{21}Fr_{21} + X_{24}Fr_{24} = 1 \qquad (5\text{-}31)$$

where:

X_n : Level of activity n (number of row planters).

Fr_m : A vector of 1 under row planter 1 (R_1--3.0m). It should be noted that row planter 1 was used to plant beans and corn within the time limit for each.

<u>Forcing the number of row cultivators to be an integer</u>:

$$X_{27}Fr_{27} + X_{30}Fr_{30} = 1 \qquad (5\text{-}32)$$

where:

X_n : Level of activity n (number of row cultivators).

Fr_m : A vector of 1 under row cultivator 1 (V_1--3m). This row cultivator existed under two columns just to indicate that the same row cultivator is used at different times of the year for beans and corn.

Forcing the number of sprayers to be an integer:

$$X_{33}Fr_{33} + X_{36}Fr_{36} = 1 \qquad (5\text{-}33)$$

where:

X_n : Level of activity n (number of sprayers).

Fr_m : A vector of 1 under sprayer (S_1--1.4m), which was set to be used for spraying the bean field and corn field at a different time.

Forcing the number of harvesters to be an integer:

$$X_{39}Fr_{39} + X_{41}Fr_{41} = 1 \qquad (5\text{-}34)$$

where:

X_n : Level of activity n (number of harvesters).

Fr_m : A vector of ones under harvester 1 (H_1--4.0m). It should be noted that the same harvester was used to harvest beans and corn but with different headers.

Forcing tractor 1 and 2 to be an integer:

$$X_9Fr_9 = 1 \qquad (5\text{-}35)$$

$$X_{10}Fr_{10} = 1 \qquad (5\text{-}36)$$

where:

X_n : Level of activity n (number of tractors).

Fr_m : A vector of 1 under tractor 1 (T_1--37.3 kw) and tractor 2 (T_2--59.7 kw).

5.5-5 Model Results

The model results indicated that a farmer can make up to $91,404.00 per year if 100 ha of land is planted with beans and 100 ha is planted with corn, which equals approximately $457.00 per hectare. The final model results are shown in Table 5-4 and were given in Figure 5-1.

5.5-6 A 25 Percent Bean-75 Percent Corn Production System

This system was studied in order to find the economic impact of having 25 percent bean and 75 percent corn (land of 50 ha beans and 150 ha corn) on the farmer's profit. The same technique followed in the 75 percent bean-25 percent corn production model was also involved in this new system but with some changes. These changes are presented according to the following constraints while the rest of the constraints remained fixed.

Forcing the land size to be 50 ha beans and 150 ha corn:

$$X_1Fr_1 = 50 \tag{5-25}$$

where:

X_1 : Level of activity 1 (size of land for planting navy beans).

Fr_1 : A vector of 1 under navy bean production.

TABLE 5-4

Summary of the Final Solution of the
50 Percent Navy Bean - 50 Percent
Corn Production Model

Items	Size	Final Solution
Land	100 ha	Navy Bean
Land	100 ha	Corn
Bean Agronomic Requirements		
Seeds		4500 kg
Fertilizer		27000 kg
Herbicide		530 kg
Corn Agronomic Requirements		
Seeds		1400 kg
Fertilizer		31000 kg
Herbicide		340 kg
Machinery Requirements		
Utility tractor	39.3 kw	1
Tillage tractor	59.7 kw	1
Chisel plow	2.4 m	1
Field cultivator	4.7 m	1
Row planter	3.0 m	1
Row cultivator	3.0 m	1
Sprayer	1.4 m	1
S.P. combine	4.0 m	1
Labor Requirements		952 hr
Total bean yield		260.6 tonne
Total corn yield		603.76 tonne
Total profit		$91404.00
Net profit per ha		457.00 $/ha

<u>Forcing the number of sprayers to be an integer</u>:

$$X_{34}Fr_{34} + X_{37}Fr_{37} = 1 \qquad (5\text{-}25)$$

where:

X_n : Level of activity n (number of sprayers).

Fr_m : A vector of 1 under sprayer 2 (S_2--1.8m) for spraying bean's field and corn's field at different time of the year.

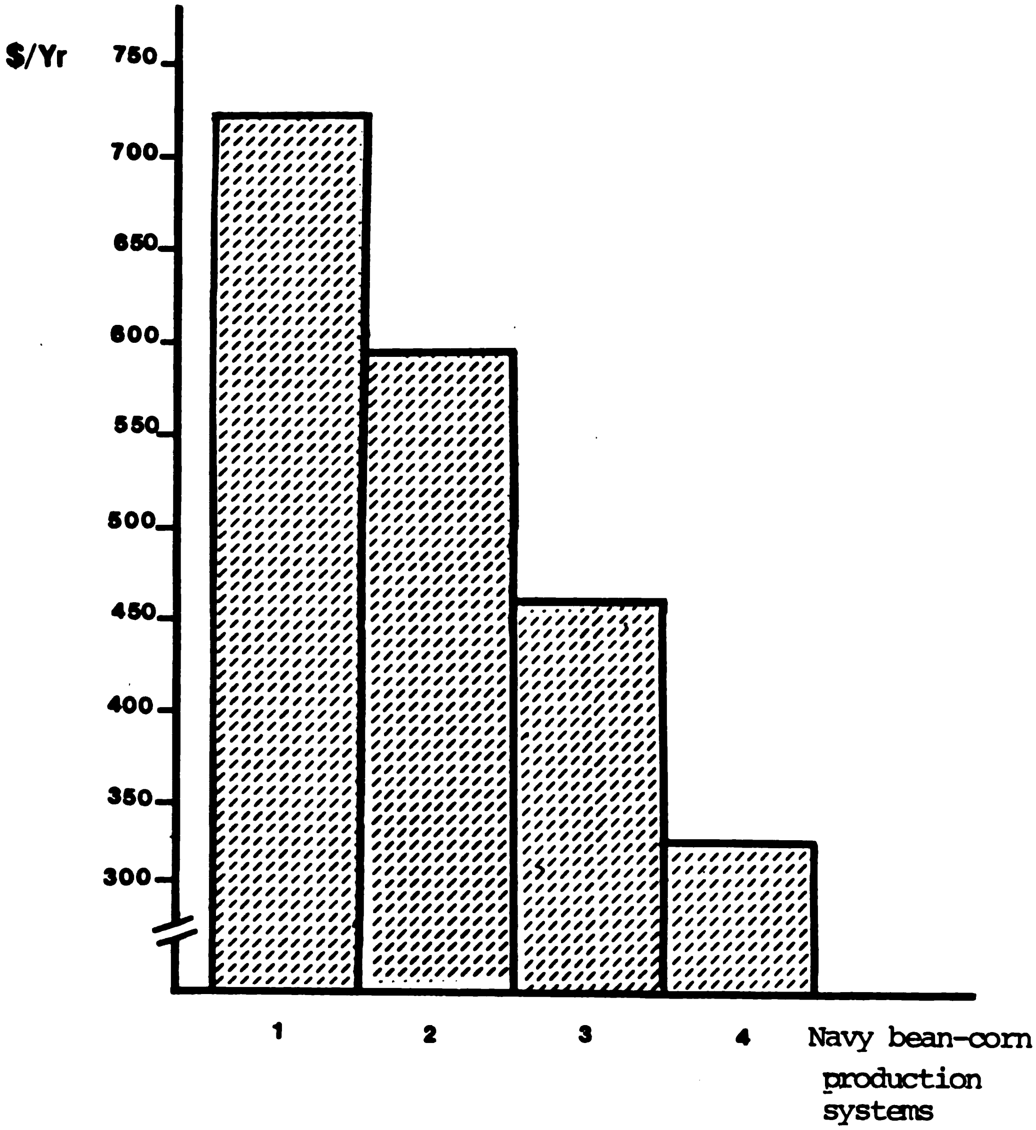
5.5-7 Model Results

The model results indicated that a farmer can make up to $64,685.00 per year if 50 ha of land is planted beans and 150 ha is planted corn, which approximately equals to $323.00 per hectare. The final model results are presented in Table 5-5 and were shown in Figure 5-1.

TABLE 5-5

Summary of the Final Solution of the
25 Percent Navy Bean - 75 Percent
Corn Production Model

Items	Size	Final Solution
Land	50 ha	Navy Bean
Land	150 ha	Corn
Bean Agronomic Requirements		
Seeds		2250 kg
Fertilizer		13500 kg
Herbicide		265 kg
Corn Agronomic Requirements		
Seeds		2100 kg
Fertilizer		46500 kg
Herbicide		510 kg
Machinery Requirements		
Utility tractor	37.3 kw	1
Tillage tractor	59.7 kw	1
Chisel plow	2.4 m	1
Field cultivator	4.7 m	1
Row planter	4.5 m	1
Row cultivator	3.0 m	1
Sprayer	2.7 m	1
S.P. combine	4.0 m	1
Labor Requirements		831.7 hr
Total bean yield		130.25 tonne
Total corn yield		951.30 tonne
Total profit		$64685.00
Net profit per ha		323.00 $/ha



1 : Optimal solution (100% bean)
2 : 75% bean and 25% corn
3 : 50% bean and 50% corn
4 : 25% bean and 75% corn

Fig. 5-1. Summary of the profits under different percentage of navy bean - corn.

6. NAVY BEANS — SUGAR BEET PRODUCTION MODEL

6.1 Model Formulation

The MILP algorithm was developed to evaluate and compare navy bean (Swan Valley variety planted in 70 cm and harvested directly) production and sugar beet production in Michigan. The objective of the model is to select the more economical crop which can be produced so that the profit can be maximized.

This model had variables which select a machinery complement from an available set of tractors (37.3, 59.7, 119.3 kw), chisel plows (2.4, 3.1, 3.4 m), field cultivators (4.7, 5.6, 6.6 m), row planters (3.0, 4.5, 6.0 m), row cultivators (3.0, 4.5, 6.0 m), sprayers (1.4, 1.8, 2.7 m), bean harvesters (4.0, 5.0 m), beet toppers (2.1, 2.8 m), and beet lifters (2.1, 2.8 m). The purchase of fractional machines was not allowed and machinery rental was not considered.

The model was formulated as a mixed integer linear programming with 47 columns (activities) and 44 rows (constraints). The following equations overview the structure.

<u>The objective function:</u>

$$\begin{aligned}\text{Maximize } Z = {} & X_1B - X_2S - X_3SB - X_4FB - X_5HB - X_6SS \\ & -X_7FS - X_8HS - X_9T_1 - X_{10}T_2 - X_{11}T_4 \\ & -X_{12}C_1 - X_{13}C_2 - X_{14}C_3 - X_{15}FB_2 - X_{16}FB_3 \\ & -X_{17}FB_4 - X_{18}FS_2 - X_{19}FS_3 - X_{20}FS_4 \\ & -X_{21}RB_1 - X_{22}RB_2 - X_{23}RB_3 - X_{24}RS_1 \\ & -X_{25}RS_2 - X_{26}RS_3 - X_{27}VB_1 - X_{28}VB_2 \\ & -X_{29}VB_3 - S_{30}VS_1 - S_{31}VS_2 - X_{32}VS_3 \\ & -X_{33}SB_1 - X_{34}SB_2 - X_{35}SB_3 - X_{36}SS_1 \\ & -X_{37}SS_2 - X_{38}SS_3 - X_{39}H_1 - X_{40}H_2 - X_{41}P_1 \\ & -X_{42}P_2 - X_{43}L_1 - X_{44}L_2 + X_{45}BS + X_{46}SBS \\ & -X_{47}LA\end{aligned}$$

where:

Z : The total net profit \$/yr.

X_n : Level of activity n, where n = 1 . . .47 (where n represents the column or activity number).

B_1 : Insecticide and fungicide cost (\$/ha) for navy bean.

S_2 : Insecticide and fungicide cost (\$/ha) for sugar beets.

SB, SS : Navy bean and sugar beet seed price (\$/kg), respectively.

FB, FS : Fertilizer cost (\$/kg) for navy beans and sugar beet production, respectively.

HB, HS : Herbicide cost (\$/kg) for navy beans and sugar beet production, respectively.

The navy bean production data required were presented in Table 3-1, while the sugar beet production data required are summarized in Table 3-4.

T_m : Annual cost of using a tractor ($/yr) where $m = 1,2,4$.

C_m : Annual cost of using a chisel plow m where $m = 1,2,3$.

FB_m : Annual cost of using field cultivator m ($/yr) for cultivating bean fields where $m = 2,3,4$.

FS_m : Annual cost of using field cultivator m ($/yr) for cultivating beet fields where $m = 2,3,4$. (It should be noted that the field cultivators used for tilling beet fields are the same ones used for cultivating bean fields).

RB_m : Annual cost of using row planter m ($/yr) for planting navy bean seeds where $m = 1,2,3$.

RS_m : Annual cost of using row planter m ($.yr) for planting sugar beet seeds where $m = 1,2,3$. (It should be noted that the row planters used for planting sugar beets are the same ones used for planting navy beans).

VB_m : Annual cost of using row cultivator m ($/yr) for cultivating bean fields where $m = 1,2,3$.

VS_m : Annual cost of using row cultivator m ($/yr) for cultivating beet fields where $m = 1,2,3$.

(It should be noted that the row cultivators involved for cultivating beet fields are the same ones used for cultivating bean fields.)

SB_m : Annual cost of using sprayer m (\$/yr) for spraying navy bean fields where m = 1,2,3.

SS_m : Annual cost of using sprayer m (\$/yr) for spraying sugar beet fields where m = 1,2,3. (Sprayers used for spraying sugar beet fields were also used for spraying navy bean fields).

H_m : Annual cost of using harvester m (\$/yr) for harvesting navy beans directly where m = 1,2.

P_m : Annual cost of using beet topper m (\$/yr) for topping sugar beets where m = 1,2.

L_m : Annual cost of using beet lifter m (\$/yr) for lifting sugar beets from the field where m = 1,2.

Table 3-8 summarizes the total annual cost for each implement used in the navy bean-sugar beet production model.

BS : Market sale price of navy beans (\$/kg).

SBS : Market sale price of sugar beets (\$/ton).

LA : Labor cost per hour (\$/hr assumed to be \$6/hr).

The objective function was maximized subject to a series of constraints illustrated by equations (6-1) through

(6-44), where the equation number represents the row number (constraint number), and the subscripted x's indicates the column number (activity number).

Land constraint:

$$X_1a_1 + X_2a_2 = b_1 \tag{6-1}$$

where:

X_n : Represents the land area (hectares) where $n = 1,2$.

a_n : Is a vector of ones (value of ones) under navy beans and sugar beet production where $n = 1,2$.

b_1 : Is a land size limitation (it was to be 200 ha).

Yield constraints:

$$-X_1Y_1 + X_{45}Y_{45} \leq 0 \tag{6-2}$$

$$-X_2Y_2 + X_{46}Y_{46} \leq 0 \tag{6-3}$$

where:

X_n : Is the level of activity n (size of land in ha) where $n = 1,45$ in the first equation and $n = 2,46$ in the second.

Y_1 : Represents the navy bean yield level (kg/ha).

Y_{45} : A vector of 1 (value of one) under selling beans activity.

Y_2 : The sugar beet yield level ton/ha.

Y_{46} : A vector of 1 under selling sugar beet activity.

Seeding rate:

$$X_1Se_1 - X_3Se_3 \leq 0 \quad (6\text{-}4)$$

$$X_2Se_2 - X_6Se_6 \leq 0 \quad (6\text{-}5)$$

where:

X_n : Level of activity n (size of land) where n = 1,3 and 2,6.

Se_1 : Amount of navy bean seed required (kg/ha).

Se_3 : A vector of -1 under navy bean seed price ($/kg).

Se_2 : Amount of sugar beet required (kg/ha).

Se_6 : A vector of -1 under sugar beet seed price ($/kg).

Fertilizer rate constraints:

$$X_1Fe_1 - X_4Fe_4 \leq 0 \quad (6\text{-}6)$$

$$X_2Fe_2 - X_7Fe_7 \leq 0 \quad (6\text{-}7)$$

where:

X_n : Level of activity n (size of land) where n = 1,4 and 2,7.

Fe_1 : Amount of fertilizer required for bean production (kg/ha).

Fe_4 : A vector of -1 under fertilizer market price ($/kg) for navy bean production.

Fe_2 : Amount of fertilizer required for sugar beet production (kg/ha).

Fe_7 : A vector of -1 under fertilizer market price ($/kg) for sugar beet production.

Herbicides rate constraints:

$$X_1He_1 - X_5He_5 \leq 0 \qquad (6\text{-}8)$$

$$X_2He_2 - X_8He_8 \leq 0 \qquad (6\text{-}9)$$

where:

X_n : Level of activity n (size of land) where n = 1,5 and 2,8.

He_1 : Amount of herbicide required for bean production (kg/ha).

He_5 : A vector of -1 one under the herbicide market price ($/kg) for bean production.

He_2 : Amount of herbicide required for sugar beet production (kg/ha).

He_8 : A vector of -1 under the herbicide market price ($/kg) for sugar beet production.

Plowing operation:

$$X_1PO_1 + X_2PO_2 - X_{12}PO_{12} - X_{13}PO_{13} - X_{14}PO_{14} \leq 0 \qquad (6\text{-}10)$$

where:

X_n : Level of activity n (number of tillage implements) where n = 1,2,12,13,14

PO_m : Is a vector of ones under bean and sugar beet production where m = 1,2.

PO_k : Is a matrix (value) of the number of hectares that chisel plow k can cover during plowing time where k = 12,13,14 (C_1, C_2, C_3).

Field cultivation:

$$X_1Ha_1 - X_{15}Ha_{15} - X_{16}Ha_{16} - X_{17}Ha_{17} \leq 0 \qquad (6\text{-}11)$$

where:

X_n : Level of activity n (number of field cultivators) where n = 1,15,16,17.

Ha_1 : A vector of 1 under bean production.

Ha_m : Is a matrix (value) of the number of hectares that field cultivator m can cover during cultivating time where m = 15 . . . 17 (F_2, F_3, F_4).

$$X_2Ha_2 - X_{18}Ha_{18} - X_{19}Ha_{19} - X_{20}Ha_{20} \leq \qquad (6\text{-}12)$$

where:

X_n : Level of activity n (number of field cultivators) where n = 1,18,19,20.

Ha_2 : A vector (value) of 1 under sugar beet production.

Ha_m : Is a matrix (value) of the number of hectares that field cultivator m can cover during cultivating time where m = 18 . . . 20 (F_2, F_3, F_4).

<u>Planting operation</u>:

$$X_1pL_1 - X_{21}pL_{21} - X_{22}pL_{22} - X_{23}pL_{23} \leq 0 \qquad (6\text{-}13)$$

where:

X_n : Level of activity n (number of row planters) where n = 1,21,22,23.

pL_1 : A vector of 1 under bean production.

pL_m : Represents the number of hectares that row planter m can cover during planting time where m = 21 . . . 23 (R_1, R_2, R_3).

$$X_2pL_2 - X_{24}pL_{24} - X_{25}pL_{25} - X_{26}pL_{26} \leq 0 \qquad (6\text{-}14)$$

where:

X_n : Level of activity n (number of row planters) where n = 1,24,25,26.

pL_2 : A vector of 1 under sugar beet production.

pL_m : Represents the number of hectares that row planter m can cover during planting time where m = 24 . . . 26 (R_1, R_2, R_3).

<u>Row cultivation</u>:

$$X_1Cu_1 - X_{27}Cu_{27} - X_{28}Cu_{28} - X_{29}Cu_{29} \leq 0 \qquad (6\text{-}15)$$

$$X_2Cu_2 - X_{30}Cu_{30} - X_{31}Cu_{31} - X_{32}Cu_{32} \leq 0 \qquad (6\text{-}16)$$

where:

X_n : Level of activity n (number of row cultivators) where n = 1,27 . . . 29 and 2, 30 . . . 32.

Cu_1, Cu_2: A vector of 1 under bean and sugar beet, production, respectively.

Cu_m : A vector of the number of hectares that row cultivator m can accomplish during culti vating time in a bean field, where m = 27 . . . 29 (V_1, V_2, V_3).

Cu_k : A vector of the number of hectares that row cultivator k can perform during cultivating time in a sugar beet field, where k = 30 . . . 32 (V_1, V_2, V_3).

<u>Spraying operation</u>:

$$X_1Sp_1 - X_{33}Sp_{33} - X_{34}Sp_{34} - X_{35}Sp_{35} \leq 0 \qquad (6\text{-}17)$$

$$X_2Sp_2 - X_{36}Sp_{36} - X_{37}Sp_{37} - X_{38}Sp_{38} \leq 0 \qquad (6\text{-}18)$$

where:

X_n : Level of activity n (number of sprayers), where n = 1,33 . . . 35 and 2, 36 . . . 38.

Sp_1, Sp_2: A vector of 1 under bean and sugar beet production, respectively.

Sp_m : Number of hectares that a field sprayer m can fulfill during spraying time in a bean field, where m = 33 . . . 35 (S_1, S_2, S_3).

Sp_k : Number of hectares that field sprayer k can perform during spraying time in a sugar beet field, where k = 36 . . . 38 (S_1, S_2, S_3).

<u>Harvesting navy bean operation</u>:

$$X_1Hr_1 - X_{39}Hr_{39} - X_{40}H4_{40} \leq 0 \qquad (6\text{-}19)$$

where:

X_n : Level of activity n (number of navy bean harvesters), where n = 1,39,40.

Hr_1 : A vector of 1 under navy bean production.

Hr_m : Number of hectares that a bean harvester can cover during the harvesting time limit, where m = 39,40 (H_1, H_2).

<u>Harvesting sugar beet</u>:

--Topping operation:

$$X_2To_2 - X_{41}To_{41} - X_{42}To_{42} \leq 0 \qquad (6\text{-}20)$$

where:

X_n : Level of activity n (number of beet toppers), where n = 2,41,42.

To_2 : A vector of 1 under sugar beet production.

To_m : The number of hectares that a topper m can cover during the harvesting time limit where $m = 41, 42$ (P_1, P_2).

--Lifting operation:

$$X_2L_2 - X_{43}L_{43} - X_{44}L_{44} \leq 0 \quad (6\text{-}21)$$

where:

X_n : Level of activity n (number of beet lifters), where n=2, 43, 44.

L_2 : A vector of 1 under sugar beet production.

L_m : Number of hectares that lifter m can perform during the harvesting time limit where m=43, 44 (L_1,L_2)

<u>Usage of tractor 1:</u>

$$-X_9Ta_9 + X_{15}Ta_{15} + X_{18}Ta_{18} + X_{21}Ta_{21} + X_{24}Ta_{24} + X_{27}Ta_{27} + X_{28}Ta_{28} + X_{30}Ta_{30} + X_{31}Ta_{31} + X_{33}Ta_{33} + X_{34}Ta_{34} + X_{35}Ta_{35} + X_{36}Ta_{36} + X_{37}Ta_{37} + X_{38}Ta_{38} + X_{41}Ta_{41} + X_{42}Ta_{42} \leq 0 \quad (6\text{-}22)$$

where:

X_n : Level of activity n (number of implements).

Ta_9 : Recommended number of hours for tractor 1 to be used for executing field operation (it was assumed to be 1,000 hrs.).

Ta_m : Number of hours under which each field operation can be performed by tractor 1 using implement m where m=15, 18, 21, 24, 27, 28, 30, 31, 33, 34, 35, 36, 37, 38, 41, 42. [The number of hours under which a field operation can be performed was calculated by dividing land area (200 ha was assumed in this model) by the implement capacity (ha/hr).]

<u>Usage of tractor 2:</u>

$$-X_{10}Ta_{10} + X_{12}Ta_{12} + X_{16}Ta_{16} + X_{17}Ta_{17} + X_{19}Ta_{19}$$
$$+X_{20}Ta_{20} + X_{22}Ta_{22} + X_{23}Ta_{23} + X_{25}Ta_{25} + X_{26}Ta_{26}$$
$$+X_{29}Ta_{29} + X_{32}Ta_{32} \leq 0 \qquad (6\text{-}23)$$

where:

X_n : Level of activity n (number of implements).

Ta_{10} : Recommended number of hours for tractor 2 to be used for executing field operations (the number of hours was assumed to be 1,000 hrs.).

Ta_m : The number of hours under which a field operation can be fulfilled by tractor 2 using implement m, where m = 12,16,17,19,20,2 23,25,26,29 and 32.

<u>Usage of tractor 4:</u>

$$-X_{11}Ta_{11} + X_{13}Ta_{13} + X_{14}Ta_{14} + X_{43}Ta_{43}$$
$$+X_{44}Ta_{44} \leq 0 \qquad (6\text{-}24)$$

where:

X_n : Level of activity n (number of implements).

Ta_{11} : Recommended number of hours for tractor 4 to be used for executing field operations (the recommended number of hours was set to be 1,000 hrs.)

Ta_m : Number of hours under which a field operation can be accomplished by tractor 4 using implement m, where m = 13,14,43,44.

<u>Labor contraints</u>:

$$\begin{aligned}
&X_{12}La_{12} + X_{13}La_{13} + X_{14}La_{14} + X_{15}La_{15} + X_{16}La_{16} \\
&+X_{17}La_{17} + X_{18}La_{18} + X_{19}La_{19} + X_{20}La_{20} + X_{21}La_{21} \\
&+X_{22}La_{22} + X_{23}La_{23} + X_{24}La_{24} + X_{25}La_{25} + X_{26}La_{26} \\
&+X_{27}La_{27} + X_{28}La_{28} + X_{29}La_{29} + X_{30}La_{30} + X_{31}La_{31} \\
&+X_{32}La_{32} + X_{33}La_{33} + X_{34}La_{34} + X_{35}La_{35} + X_{36}La_{36} \\
&+X_{37}La_{37} + X_{38}La_{38} + X_{39}La_{39} + X_{40}La_{40} + X_{41}La_{41} \\
&+X_{42}La_{42} + X_{43}La_{43} + X_{44}La_{44} + X_{47}La_{47} < 0
\end{aligned} \tag{6-25}$$

where:

X_n : Level of activity n (number of implements) where n=12...44 and 47.

La_m : Represents the number of hours required to accomplish a field operaiton for a land size of 200 ha, where m=12...44 (the summary of the number of hours available for each field operation are shown in Tables 3-14 and 3-16.

La_{47} : Is a vector of -1 which implies the summation of all the number of hours required for navy bean and corn production for calculating the labor cost.

The number of hours required for each implement to accomplish a field work are presented in Table 6-1.

TABLE 6-1

The Land Area that can be Covered by an Implement During the Available Workable Days and the Time Required to Cover 200 Ha

Implement	Code	Number of Hectares*	Number of Hours**
Chisel plow	C_1	200	135
Chisel plow	C_2	255	105
Chisel plow	C_3	270	100
Field cultivator	F_2	393	66.6
Field cultivator	F_3	480	55.5
Field cultivator	F_4	579	43.2
Row planter	R_1	117	178
Row planter	R_2	174	91.7
Row planter	R_3	232	68.7
Row cultivator	V_1	200	164
Row cultivator	V_2	299	109
Row cultivator	V_3	397	82
Sprayer	S_1	120	274
Sprayer	S_2	160	200
Sprayer	S_3	236	135
Beet topper	T_1	161	285
Beet topper	T_1	216	213
Beet lifter	L_1	161	285
Beet lifter	L_2	216	213

*Number of hectares = [field capacity of an implement (ha/hr)] x number of hours available for field work (hr)]

**Number of hours = [land size (ha)] ÷ [field capacity of an implement (ha/hr)]

The initial result obtained from this model indicated that planting sugar beets was more profitable to the farmers than planting navy beans. However, the number of implements selected by the model were fractional numbers rather than intergers which is not feasible. Therefore, some constraints were added to the model to force the previous kinds of implements to be in intergers. These constraints were listed as follows:

<u>Forcing the number of chisel plows to be an interger:</u>

$$X_{12}Fr_{12} + X_{13}Fr_{13} + X_{14}Fr_{14} = 1 \qquad (6\text{-}26)$$

$$X_{12}Fr_{12} \leq 1 \qquad (6\text{-}27)$$

$$X_{13}Fr_{13} \leq 1 \qquad (6\text{-}28)$$

$$X_{14}Fr_{14} \leq 1 \qquad (6\text{-}29)$$

where:

X_n : Level of activity n (number of chisel plows).

Fr_m : A vector of ones for m=12, 13, 14. These vectors of ones were set only under the size of chisel plow that can cover 200 ha or more within the time limit to guarantee that the number of tillage implements was an interger.

<u>Forcing the number of field cultivators to be an integer:</u>

$$X_{18}Fr_{18} + X_{19}Fr_{19} + X_{20}Fr_{20} = 1 \qquad (6\text{-}30)$$

$$X_{18}Fr_{18} \leq 1 \qquad (6\text{-}31)$$

$$X_{19}Fr_{19} \leq 1 \qquad (6\text{-}32)$$

$$X_{20}Fr_{20} \leq 1 \qquad (6\text{-}33)$$

where:

X_n : Level of activity n (number of field cultivators).

Fr_m : A vector of ones for m=18, 19, 20.

<u>Forcing the number of row planters to be an integer:</u>

$$X_{26}Fr_{26} = 1 \tag{6-34}$$

where:

X_{26} : Level of activity (number of row planters).

Fr_{26} : A vector of 1 under only row planter 3 that can cover 200 ha within the time limit.

<u>Forcing the number of row cultivators to be integer:</u>

$$X_{30}Fr_{30} + X_{31}Fr_{31} + X_{32}Fr_{32} \tag{6-35}$$

$$X_{30}Fr_{30} \leq 1 \tag{6-36}$$

$$X_{31}Fr_{31} \leq 1 \tag{6-37}$$

$$X_{32}Fr_{32} \leq 1 \tag{6-38}$$

where:

X_n : Level of activity n (number of row cultivators).

Fr_m : A vector of ones under row cultivators number 1, 2 and 3 because they are capable of cultivating 200 ha or more within the time limit.

<u>Forcing the number of sprayers to be an integer:</u>

$$X_{38}Fr_{38} = 1 \tag{6-39}$$

where:

X_n : Level of activity n (number of sprayers).

Fr_m : A vector of 1 under sprayer number 3 which is capable of harvesting 200 ha within the time limit.

Forcing the number of toppers and lifters to be an integer:

$$X_{42}Fr_{42} = 1 \quad (6\text{-}40)$$

$$X_{44}Fr_{44} = 1 \quad (6\text{-}41)$$

where:

X_n : Level of activity n where n=42, 44.

Fr_{42} : A vector of 1 under topper 2 which can cover 200 ha or more within the harvesting time limit.

Fr_{44} : A vector of 1 under lifter 2 which can cover 200 ha or more within the harvesting time limit.

Forcing the number of tractors to be integer:

$$X_9Fr_9 = 1 \quad (6\text{-}42)$$

$$X_{10}Fr_{10} = 1 \quad (6\text{-}43)$$

$$X_{11}Fr_{11} = 1 \quad (6\text{-}44)$$

where:

X_n : Level of activity n (number of tractors).

Fr_m : A vector of ones under tractor 1 (T_1.. 37.3 kw). and tractor 2 (T_2 . . . 59.7 kw) and tractor 4 (T_4 . . . 119.3 kw).

6.2 Model Adjustment

In the MILP model the tractor usage was assumed to be 1000 hours per year to estimate the annual cost of using tractor 1, 2, and 4. However, the results obtained from the navy bean production model indicated that the actual number of hours for the tractor usage were found as follows:

1. Utility tractor 1 (T_1 - 37.3 kw) : 648 hours per year, 300 hours of which were assumed to be used for nonfarming activities (handling, transportation, turns, etc.).
2. Tillage tractor 2 (T_2 - 59.7 kw) : 307 hours per year, 100 hours of which were assumed to be for nonfarming activities (handling, transportation, turns, etc.).
3. Tillage tractor 4 (T_4 - 119.3 kw) : 413 hours per year, 100 hours of which were assumed to be used for nonfarming activities.

These actual number of hours for tractor usage were fed in the machinery cost model by Rotz et al. (1981) to calculate the total annual cost for using tractor 1, 2, and 4. The results obtained from the machinery cost model are summarized in Table 6.2.

TABLE 6-2

Summary of the Adjusted Annual Cost
of Tractors 1, 2, 3 Over
Ten Year Period

Implement	Code	Ownership Cost	Repair & Maintenance	Fuel	Total Present Value	Average Annual Cost
Utility tractor	T1	8050	5272	26214	39536	4401
Tillage tractor	T2	12887	2554	19877	35318	3932
Tillage tractor	T3	25748	8202	53436	87386	9728

6.3 Model Results

The results obtained from the navy bean - sugar beet production model indicated that under present sugar beet yield level (50 ton/ha) and market price of (30 $/ton), producing sugar beets was more beneficial to the farmers. A farmer could make up to $214,066.00 profit from 200 ha of land which equals approximately $1,070.00 per ha. The summary of the navy bean - sugar beet model results are presented in Table 6-3. These results illustrate the amount of seed, fertilizer, and herbicides required for sugar beet planted in 200 ha and represent the kinds and sizes of implements selected by the model.

6.4 Sensitivity Analysis

6.4-1 Shadow Prices and Slacks

Shadow price indicates the impact of increasing the right hand side for a linear programming constraint by one unit. While the slack variable represents the amount of unused resource. In the navy bean - sugar beet production model, the shadow price and slack variables for the available resources were analyzed by the computer. The results obtained from these analyses are summarized in Table 6-4.

TABLE 6-3

Summary of the Final Solution of the Navy Bean - Sugar Beet Production Model

Items	Size	Final Solution
Land Size	200 ha	Sugar Beet
Beet Agronomic Requirements		
Seeds		266 kg
Fertilizer		69000 kg
Herbicide		340 kg
Machinery Requirements		
Utility tractor	37.3 kw	1
Tillage tractor	59.7 kw	1
Tillage tractor	119.3 kw	1
Chisel plow	3.4 m	1
Field cultivator	6.6 m	1
Row planter	6.0 m	1
Row cultivator	6.0 m	1
Sprayer	2.7 m	1
Beet topper	2.8 m	1
Beet topper	2.8 m	1
Labor Requirements		872 hr
Total beet yield		10000 tonne
Total profit		$214066.00
Total net profit per ha		1070.00 $/ha

TABLE 6-4

Summary of the Shadow Prices and the Slacks Obtained from the Navy Bean-Sugar Beet Production Model

Items	Unit	Shadow Price Value	Slack Value
Land	$/ha	1233.70	
Yield	$/tonne	30.00	
Seed	$/kg	45.00	
Fertilizer	$/kg	.41	
Herbicides	$/kg	20.00	
Plowing	$/ha		55
Field cultivation	ha		379
Sugar beet planting	ha		32
Row cultivation	ha		197
Spraying	ha		36
Beet topping	ha		16
Beet lifting	ha		16
Using tractor 1	hr		652
Using tractor 2	hr		793
Using tractor 4	hr		687
Labor	$/hr	6.00	

These results indicate the following:

1. If the farmer is going to rent one more hectare of land, he is willing to pay up to $1233.7 per year, otherwise it is not profitable to pay more than this value.
2. If the farmer is going to sell his crop, he is willing to accept $30 per ton and up.
3. If the farmer is going to purchase one more kg of sugar beet seeds, fertilizer, and herbicide, he is willing to pay up to 45, 0.41, and 20 $/kg, respectively.
4. By using chisel plow 3 (C_3 - 3.4 m), and field cultivator 4 (F_4 - 6.6 m), the farmer will have excess 55, and 379 hectare of land, respectively. (Land can be covered in addition to 200 ha of land assumed by the MILP model.)
5. By using row planter 3 (R_3 - 6.0 m), row cultivator 3 (V_3 - 6.0 m), and sprayer 3 (S_3 - 2.7 m), the farmer will have excess 32,197, and 36 hectares of land, respectively.
6. By using beet topper 2 (P_2 - 2.8 m) and beet lifter 2 (L_2 - 2.8 m) for harvesting beets, the farmer will have excess 16 hectare of land to cover for each implement.

7. By using tractor 1 (T_1 - 37.3 kw), tractor 2 (T_2 - 59.7 kw) and tractor 4 (T_4 - 119.3 kw) the farmer will have excess 652, 793, and 687 hours per year, respectively to cover 1000 hours of tractor usage per year.
8. If the farmer is going to use additional employees to fulfill the field work, he is willing to pay $6.0 per hour for each employee.

6.4-2 The Cost of Forcing Nonoptimal Activities into Optimal Solution

The cost of forcing nonoptimal activities into optimal solution is an economics term used to indicate the impact of forcing nonoptimal activities into final solution. The results obtained from the computer analysis indicated the following:

1. Using chisel plow 1 (C_1--2.4-m) instead of chisel plow 3 (C_3--3.4m) to plow the sugar beet field, would cost the farmer $1,270.00 per year.
2. Using field cultivator 2 (F_2--4.7-m) instead of field cultivator 4 (F_4--6.6m) for tilling the sugar beet field would increase the total annual cost by $842.00.

3. Using row planter 1 (R_1--3.0m) or row planter 2 (R_2--4.5 m) instead of row planter 3 (R_3--6.0m) would increase the total annual cost by $2,003.00 and $1,903.00 respectively.
4. Cultivating the sugar beet field by row cultivator 1 (V_1--3.0 m) instead of row cultivator 3 (V_3--6.0 m) would increase the total annual cost by $229.00.
5. Applying chemicals by sprayer 1 (S_1--1.4 m) or sprayer 2 (S_2--1.86 m) instead of sprayer 3 (S_3--2.7m) would cost $2,022.00 and $1,591.00 per year, respectively.
6. Using beet topper 1 (P_1--2.1 m) in the sugar beet harvesting process instead of beet topper 2 (P_2--2.8m) would increase the total annual cost by $3,032.00.
7. Lifting the sugar beet by beet lifter 1 (L_1--2.1 m) instead of beet lifter 2 (L_2--2.8m) would cost the farmer $4,624.00 per year.

It should be noted from these results that forcing an implement into the final solution would also force the corresponding tractor (T_1, T_2, or T_4) to be in the final solution. This would result in some additional cost attributed to the cost of using a tractor in the total annual cost of an operation.

6.4-3 Range of Optimality

Range of optimality is an economics term used to indicate the range of values over which the objective function coefficient for a variable may change without changing the optimal solution. The results obtained from the computer analysis indicated the following:

1. Producing sugar beets instead of navy beans would still be in the optimal solution as long as the insecticide and fungicide cost per hectare does not exceed $400.30.
2. The optimal solution of the navy bean - sugar beet production model can be held as long as the price of sugar beet seeds, fertilizer, and herbicides per kilogram is less than $363.86, $1.45 and $231.95 respectively.
3. Using chisel plow 3 (C_3--3.4 m) would no longer be in the optimal solution, if the annual cost of using this implement exceeds $862.58 per year. In this case, chisel plow 2 (C_2--3.1 m) would be the candidate to replace it.

4. Field cultivator 4 (F_4--6.6 m) would still be in the optimal solution as long as the total annual cost is less than $906.13. Otherwise, field cultivator 3 (F_3--5.6 m) would be the competitive implement to replace it.
5. Using row planter 3 (R_3--6.0 m) would still be in the optimal solution as long as the annual cost for the planter does not exceed $2,689.00. Otherwise, row planter 2 (R_2--4.5 m) would be the alternative implement to replace it.
6. The use of row cultivator 3 (V_3--6.0 m) would be in the optimal solution as long as the annual cost for the cultivator does not exceed $1,239.12. Otherwise, row cultivator 2 (V_2--4.5 m) would be the candidate for replacing it.
7. Using sprayer 3 (S_3--2.77 m) would no longer be in the optimal solution if the annual cost of using that implement exceeds $2,607.00. In this case, sprayer 2 (S_2--1.86 m) would be the competitive for replacing it.
8. The use of beet topper 2 (P_2--2.8 m) would still be in the optimal solution as long as the annual cost does not exceed $3,862.69; if so, beet topper 1 (P_1--2.1 m) would be the candidate to replace it.

9. Lifting the sugar beets by lifter 2 (L_2--2.8 m) would still be in the optimal solution as long as the annual cost does not exceed $8,492.86. Otherwise, beet lifter 1 (L_1--2.1 m) would be the candidate to replace it.
10. Using tractor 1 (T_1--37.7-kw), or tractor 2 (59.7 kw), or tractor 4 (T_4--119.3-kw) in the farming process depends upon the corresponding equipment that can be matched with a tractor.
11. This optimal solution can be held as long as the sugar beet market price is more than $22.79/tonne. Otherwise producing navy beans would be more profitable.
12. In the consideration of labor, the optimal solution can be held as long as the wage of labor is $8.00/hr or less.

6.5 Testing Different Percentages of Navy Beans and Sugar Beet in the Navy Bean-Sugar Beet Production Model

6.5-1 A 75 Percent Sugar Beet - 25 Percent Navy Bean Production Model

In order to study the impact of having a system of 75 percent beets and 25 percent beans (150 ha beets and 50 ha beans) on the farmer's profit, some changes took place in the previous navy bean - sugar beet production model. It was obvious that although the same field operations had to be accomplished with the same implements for both navy bean and sugar beet fields, the execution time and the time limit were different for some of these field operations. Therefore, constraints number 26-40 were substituted from the previous model by the following constraints to satisfy the new condition and to have integer number of implements.

<u>Forcing the sugar beet land size to be 150 ha</u>:

$X_2Fr_2 = 150$

where:

X_2 : Is a level of activity 1 (planting sugar beet).

Fr_2 : A vector of 1 under sugar beet production.

<u>Forcing the number of chisel plows to be integer</u>:

$$X_{12}Fr_{12} + X_{13}Fr_{13} + X_{14}Fr_{14} = 1 \qquad (6\text{-}27)$$

$$X_{12}Fr_{12} \leq 1 \qquad (6\text{-}28)$$

$$X_{13}Fr_{13} \leq 1 \qquad (6\text{-}29)$$

$$X_{14}Fr_{14} \leq 1 \qquad (6\text{-}30)$$

where:

X_n : Level of activity n (number of chisel plows).

Fr_m : A vector of ones under chisel plow 1,2,3. It should be noted that these vectors of ones were set under the size of chisel plow that could cover 200 ha or more because the plowing time for both crops was set to be at the same time of the year.

<u>Forcing the number of field cultivators to be an integer</u>:

$$X_{15}Fr_{15} + X_{18}Fr_{18} = 1 \qquad (6\text{-}31)$$

where:

X_m : Level of activity n (number of field cultivators).

Fr_m : A vector of ones under field cultivator 2 (F_2--4.7 m). It should be noted that the same field cultivator (F_2--4.7 m) was used to cultivate the navy bean land and the sugar beet land because the cultivating time was different for both crops and F_2 was capable of covering the land size for each crop within the time limit.

<u>Forcing the number of row planters to be an integer:</u>

$$X_{22}Fr_{22} + X_{25}Fr_{25} = 1 \qquad (6\text{-}32)$$

where:

X_n : Level of activity n (number of row planters, R_2).

Fr_m : A vector of ones under row planter 2 (R_2 --4.5 m), which was capable of planting 150 ha of sugar beet and 50 ha of navy bean in different time with respect to the time limit for each crop.

<u>Forcing the number of row cultivators to be an integer:</u>

$$X_{27}Fr_{27} + X_{30}Fr_{30} = 1 \qquad (6\text{-}33)$$

where:

X_n : Level of activity n (number of row cultivators, V_1).

Fr_m : A vector of ones under row cultivator 1 (V_1--3.0 m). This row cultivator existed under the two columns because of the same reasons stated above.

<u>Forcing the number of sprayers to be an integer:</u>

$$X_{34}Fr_{34} + X_{37}Fr_{37} = 1 \qquad (6\text{-}34)$$

where:

X_n : Level of activity n (number of sprayers).

Fr_m : A vector of ones under sprayer 2 (S_2 - 1.86 m).

<u>Forcing the number of harvesters to be an integer:</u>

$$X_{39}Fr_{39} = 1 \qquad (6\text{-}35)$$

where:

X_n : Level of activity n (number of bean harvesters, H_1).

Fr_m : A vector of 1 under harvester 1 (H_1--4.0 m)

<u>Forcing the number of beet topper to be an integer</u>:

$$X_{41}Fr_{41} = 1 \tag{6-36}$$

where:

X_n : Level of activity n (number of beet toppers, P_1).

Fr_m : A vector of 1 under beet topper 1 (P_1--2.1 m). It should be noted that this implement was capable of executing 150 ha within the time limit.

<u>Forcing the number of beet lifters to be an integer</u>:

$$X_{43}Fr_{43} = 1 \tag{6-37}$$

where:

X_n : Level of activity n (number of beet lifters).

Fr_m : A vector of 1 under beet lifter 1 (L_1--2.1 m). It should be noted that this implement was capable of covering 150 ha within the time limit.

<u>Forcing tractor 1 and 4 to be an integer</u>:

$$X_9Fr_9 = 1 \tag{6-38}$$

$$X_{11}Fr_{11} = 1 \tag{6-39}$$

where:

X_n : Level of activity n (number of tractors).

Fr_m : A vector of ones under tractor 1 (T_1--37.3 kw) and tractor 4 (T_4--119.3 kw).

6.5-2 Model Adjustment

It was found from the previous navy bean-sugar beet model results that the total net profit jumped up 10 percent after the model had adjusted by involving the actual number of hours for tractor usage. Therefore, in the following navy bean-sugar beet production systems, a correction term of 10 percent will be added to the total net profit for each system to get more realistic figure about the profit.

6.5-3 Model Results

The results obtained from this model indicated that a farmer could make up to $183,406.00 per year on 200 ha of land of which 150 ha was planted with sugar beets and 50 ha planted with navy beans, which equals approximately $917 per hectare. The final results of this model were further improved by eliminating tractor 2 (T_2--59.7 kw) and operating row planter 2 (R_2--4.5 m) with tractor 4 (T_4--119.3 kw) instead. This procedure caused the total profit to jump up to $194,661.00, which equals approximately $973 per hectare, Table 6-5 and Figure 6-1 represent the final results of this model.

TABLE 6-5

Summary of the Final Solution of the
25 Percent Navy Bean - 75 Percent
Sugar Beet Production Model

Items	Size	Final Solution
Land	50 ha	Navy Bean
Land	150 ha	Sugar Beet
Bean Agronomic Requirements		
Seeds		2250 kg
Fertilizer		1350 kg
Herbicide		265 kg
Beet Agronomic Requirements		
Seeds		169 kg
Fertilizer		51750 kg
Herbicide		255 kg
Machinery Requirements		
Utility tractor	37.3 kw	1
Tillage tractor	119.3 kw	1
Chisel plow	3.1 m	1
Field cultivator	3.8 m	1
Row planter	4.5 m	1
Row cultivator	3.0 m	1
Sprayer	1.8 m	1
S.P. combine	4.0 m	1
Beet topper	2.1 m	1
Beet lifter	2.1 m	1
Labor Requirements		1371 hr
Total bean yield		130.25 tonne
Total beet yield		7500 tonne
Total profit		$194661.00
Total net profit per ha		973.00 $/ha

6.5-4 A 50 percent Sugar Beet - 50 percent Navy Bean Production Model

In order to study the economic impact of having a farm with 50 percent beans and 50 percent sugar beet (a land of 100 ha sugar beet and 100 ha navy beans), on the farmer's profit, some changes took place in the main sugar beet - navy bean production model. These changes included the following:

1. Deleting constraints number 26 to 45.
2. Adding instead the following constraints to satisfy the new production condition.

<u>Forcing the size of land to be 50 percent sugar beet and 50 percent navy beans</u>:

$$X_1Fr_1 = 100 \qquad (6\text{-}26)$$

where:

X_1 : Level of activity 1 (land size for navy bean production).

Fr_1 : A vector of 1 under navy bean production.

<u>Forcing the number of chisel plow to be an integer</u>:

$$X_{12}Fr_{12} + X_{13}Fr_{13} + X_{14}Fr_{14} = 1 \qquad (6\text{-}27)$$

$$X_{12}Fr_{12} \leq 1 \qquad (6\text{-}28)$$

$$X_{13}Fr_{13} \leq 1 \qquad (6\text{-}29)$$

$$X_{14}Fr_{14} \leq 1 \qquad (6\text{-}30)$$

where:

X_n : Level of activity n (number of chisel plows).

Fr_m : A vector of ones under chisel plow 1,2 and 3, which are capable of plowing 200 ha of land within the plowing time limit.

Forcing the number of field cultivators to be an integer:

$$X_{15}Fr_{15} + X_{18}Fr_{18} = 1 \qquad (6\text{-}31)$$

where:

X_n : Level of activity n (number of field cultivators, F_2).

Fr_m : A vector of ones under field cultivator 2 (F_2--4.7 m). It should be noted that since field cultivator 2 (F_2--4.7 m) was used to cultivate both bean land and the sugar beet land, and the execution time was different, F_2 was capable of covering the land size for each crop within the time limit.

Forcing the number of row planters to be an integer:

$$X_{21}Fr_{21} + X_{24}Fr_{24} = 1 \qquad (6\text{-}32)$$

where:

X_n : Level of activity n (number of row planters, R_1).

Fr_m : A vector of ones under row planter 1 (R_1 --3.0 m). It should be noted that although the row planter existed under columns 21 and 24, these columns referred to the same row planter (R_1--3.0 m) because the planting operation was performed at different times for beans and sugar beets.

<u>Forcing the number of row cultivators to be an integer</u>:

$$X_{27}Fr_{27} + X_{30}Fr_{30} = 1 \qquad (6\text{-}33)$$

where:

X_n : Level of activity n (number of row cultivators, V_1).

Fr_m : A vector of ones under row cultivator 1 (V_1--3 m). This row cultivator existed under two columns because of the same reasons stated above.

<u>Forcing the number of sprayers to be an integer</u>:

$$X_{33}Fr_{33} + X_{36}Fr_{36} = 1 \qquad (6\text{-}34)$$

where:

X_n : Level of activity n (number of sprayers, S_1).

Fr_m : A vector of 1 under sprayer 1 (S_1--1.4 m).

<u>Forcing the number of harvesters to be an integer</u>:

$$X_{39}Fr_{39} = 1 \qquad (6\text{-}35)$$

where:

X_n : Level of activity n (number of harvesters, H_1).

Fr_m : A vector of 1 under harvester 1 (H_1--4 m).

Forcing the number of beet toppers to be an integer:

$$X_{41}Fr_{41} = 1 \qquad (6\text{-}36)$$

where:

X_n : Level of activity n (number of beet toppers, P_1).

Fr_m : A vector of one under beet topper 1 (P_1--2.1 m)

Forcing the number of beet lifters to be an integer:

$$X_{43}Fr_{43} = 1 \qquad (6\text{-}37)$$

where:

X_n : Level of activity n (number of beet lifters, L_1).

Fr_m : A vector of 1 under beet lifter 1 (L_1--2.1 m).

Forcing the number of tractor 1 and 4 to be an integer:

$$X_9Fr_9 = 1 \qquad (6\text{-}38)$$

$$X_{11}Fr_{11} = 1$$

where:

X_n : Level of activity n (number of tractors, T_1 and T_4).

Fr_m : A vector of 1 under tractor 1 (T_1--37.3 kw) and tractor 4 (T_4--119.3 kw).

6.5-5 Model Results

The results obtained from the 50 percent sugar beet - 50 percent navy bean model indicated that a farmer could make up to $174,966.00 per year if a land of 100 ha planted sugar beets and 100 ha planted navy bean, which equals $875.00 per hectare. The final results of this model are presented in Table 6-6 and were shown in Figure 6-1.

6.5-6 A 25 Percent Sugar Beet - 75 Percent Navy Bean Production Model

This system was studied in order to find the economic impact of having 25 percent sugar beets (50 ha) and 75 percent navy beans (150 ha) on the farmer's profit. The same technique followed previously in the 75 percent sugar beet-25 percent navy bean model was also involved in this new system, but with new considerations required as to the land size and sprayer size. The following constraints represent the only changes taken place in the previous model.

TABLE 6-6

Summary of the Final Solution of the 50 Percent Navy Bean - 50 Percent Sugar Beet Production Model

Items	Size	Unit	Final Solution
Land		100 ha	Navy Bean
Land		100 ha	Sugar Beet
Bean Agronomic Requirements			
Seeds			4500 kg
Fertilizer			27000 kg
Herbicide			530 kg
Beet Agronomic Requirements			
Seeds			113 kg
Fertilizer			34500 kg
Herbicide			170 kg
Machinery Requirements			
Utility tractor		37.3 kw	1
Tillage tractor		119.3 kw	1
Chisel plow		3.1 m	1
Field cultivator		3.8 m	1
Row planter		3.0 m	1
Row cultivator		3.0 m	1
Sprayer		1.4 m	1
S.P. combine		4.0 m	1
Beet topper		2.1 m	1
Beet lifter		2.1 m	1
Labor Requirements			1492.0 hr
Total bean yield			260.5 tonne
Total beet yield			5000 tonne
Total profit			$174966.00
Total net profit per ha			875.00 $/ha

<u>Forcing the land size to be 50 ha sugar beet and 150 ha navy beans</u>:

$$X_1 Fr_1 = 150 \qquad (6\text{-}26)$$

where:

X_1 : Level of activity 1 (navy bean production).

Fr_m : A vector of 1 under navy bean production.

<u>Forcing the number of sprayers to be an integer</u>:

$$X_{35} Fr_{35} + X_{38} Fr_{38} = 1 \qquad (6\text{-}34)$$

where:

X_n : Level of activity n (number of sprayers).

Fr_m : A vector of 1 under sprayer 3 (S_3--2.7m) for spraying sugar beet fields and navy bean fields.

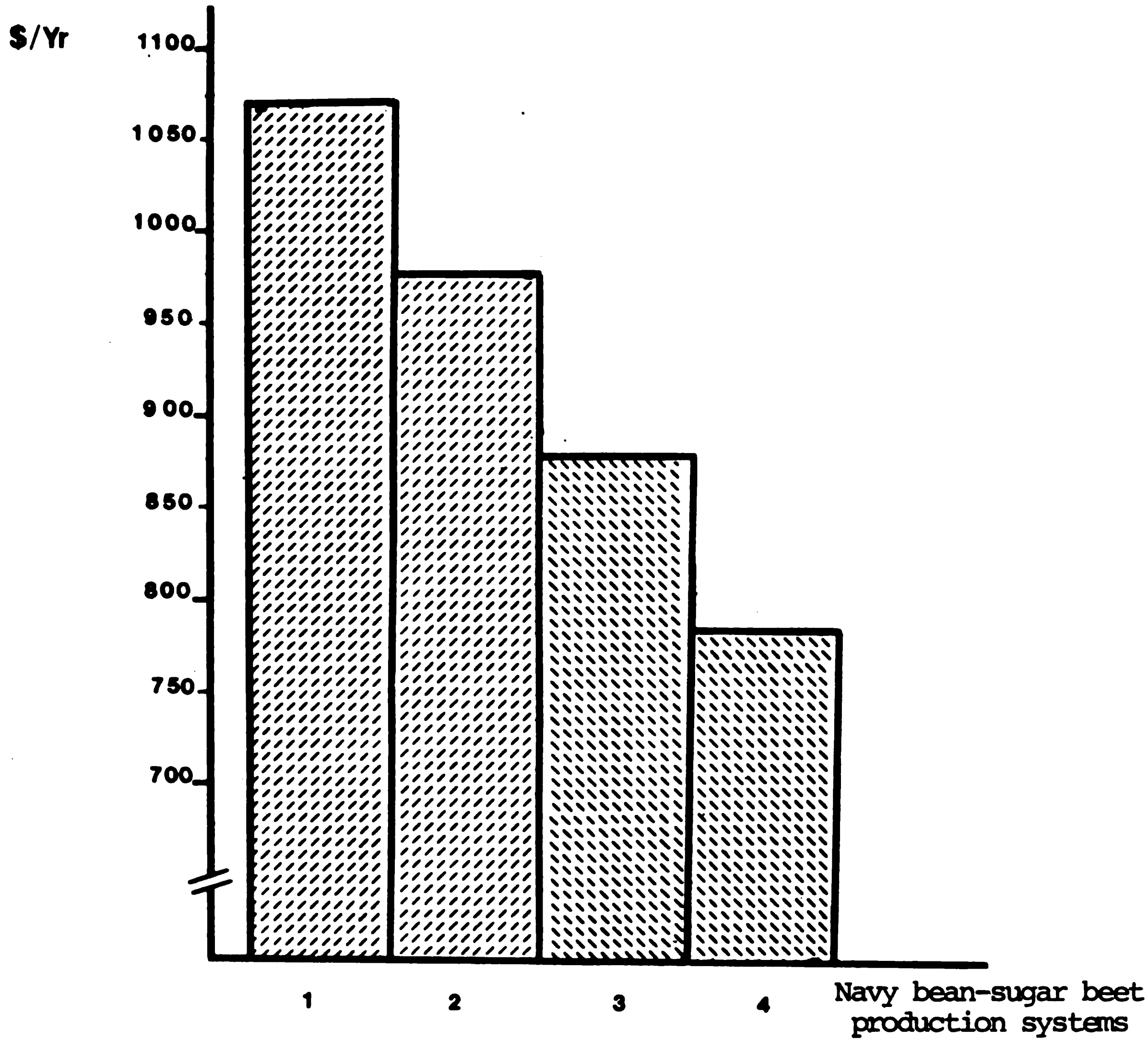
6.5-7 Model Results

The results obtained from the 25 percent sugar beet - 75 percent navy bean production model indicated that a farmer could make up to $155,856.00 per year, with land of 50 ha planted sugar beet and 150 ha planted navy bean, which equals $779.00 per hectare. The final results of this model are presented in Table 6-7 and were shown in Figure 6-1.

TABLE 6-7

Summary of the Final Solution of the
75 Percent Navy Bean - 25 Percent
Sugar Beet Production Model

Items	Size	Final Solution
Land	150 ha	Navy Bean
Land	50 ha	Sugar Beet
Bean Agronomic Requirements		
Seeds	kg	6750 kg
Fertilizer	kg	40500 kg
Herbicide	kg	795 kg
Beet Agronomic Requirements		
Seeds	kg	56.5 kg
Fertilizer	kg	17250.0 kg
Herbicide	kg	85.0 kg
Machinery Requirements		
Utility tractor	37.3 kw	1
Tillage tractor	119.3 kw	1
Chisel plow	3.1 m	1
Field cultivator	3.8 m	1
Row planter	4.5 m	1
Row cultivator	3.0 m	1
Sprayer	2.7 m	1
S.P. combine	4.0 m	1
Beet topper	2.1 m	1
Beet lifter	2.1 m	1
Labor Requirements		1306.7 hr
Total bean yield		390.75 tonne
Total beet yield		2500 tonne
Total profit		$155856.00
Total net profit per ha		779.00 $/ha



1 : Optimal solution (100% beet)
2 : 75% sugar beet and 25% navy bean
3 : 50% sugar beet and 50% navy bean
4 : 25% sugar beet and 75% navy bean

Fig. 6-1. Summary of the profits under different percentage of sugar beet - navy bean.

7 SUMMARY AND CONCLUSIONS

7.1 Summary

With the development of the new high-yielding navy bean variety (Swan Valley), it was believed that its productivity could be further improved by using a different production management system (Kelly et al., 1981).

Two navy bean varieties, Swan Valley (upright), and Fleetwood (standard), were tested to study the economic aspects of the conventional navy bean production system versus the direct harvesting production system. Swan Valley and Fleetwood varieties were planted in 70 cm and 35 cm rows. Beans planted in wide rows (70 cm) were harvested directly and conventionally, while beans planted in narrow rows (35 cm) were havested directly only.

The results obtained during the field experiemental stage indicated that Swan Valley planted in 70 cm rows and harvested directly tended to give the best results compared to other alternative navy bean production systems. These results might be attributed to the high yield level of Swan Valley compared to Fleetwood and to the crop lodging problem in the narrow row systems.

A mixed-integer linear programming technique was used to find the appropriate decisions as to which variety to plant (Swan Valley or Fleetwood), what planting system to follow (wide rows or narrow rows), which havesting method to apply (direct or conventional) and which machinery set to use in the production with consideration of the following aspects:

1. The number of suitable hours available for field work with a .8 probability level was calculated by using the model of Rotz et al. (1981) about predicting the number of suitable days available for field work in Michigan.
2. The total annual costs of using different types of implements available in today's market were calculated depending upon the fixed/variable cost model by Rotz et al. (1981).
3. The power required to match each implement with an appropriate tractor size was calculated depending upon the fixed/variable cost model by Rotz et al. (1981).
4. The agronomical requirements for both navy bean production systems were collected according to the recommendations given by the same extension bulletin and the actual application in the navy bean experiment station in Saginaw.

The navy bean production model was developed as a mixed-integer linear programming formulation with 44 columns and 38 rows. The results obtained from this model indicated that planting Swan Valley variety in 70 cm row spacing and applying the direct harvesting method was the most profitable system that could be followed. A navy bean producer could make up to $144,604.00 per year profit from 200 ha land which equals $723.00 per hectare.

The amount of navy bean seed, fertilizers, and herbicides required for a land size of 200 ha was found to be 9000, 54000, and 1060 kilograms, respectively. The results also indicated the types and sizes of implements involved in the previous navy bean production system.

Because of the fluctuation of a crop's market prices, it was desireable to study the impact of having two mixed crop systems (navy bean-corn, and navy bean-sugar beet) on the farmer's profit in Michigan. A mixed-integer linear programming technique was also involved to find the best economical crop which could be produced, and the profit value could be made under different percentages of the mixed crop system considering the machinery requirements in each production system.

The navy bean-corn production model was formulated as a mixed-integer linear programming formulation with 45 columns and 39 rows. The navy bean-corn model results indicated that under the present corn yield level (6037.00 kg/ha) and market price (0.93 $/kg), navy bean production was more profitable than corn. This optimal solution could be held as long as the navy bean market price was higher than $0.2 per kg, and the corn market price was lower than $0.19 per kg.

The results obtained from planting different percentages of beans and corn applying different MILP models indicated the following:

1. By planting 150 ha of beans 50 ha corn (75 percent beans and 25 percent corn), a navy bean producer could make $119,662.00 profit which equals $598.00 per hectare.
2. By planting 100 ha beans and 100 ha corn (50 percent beans and 50 percent corn), navy bean producers could make up to $91,404.00 per year which equals $457 per hectare.
3. By planting 50 ha of land of beans and 150 ha of corn (25 percent beans and 75 percent corn) the farmer would make only $64,685.00. This profit is equivalent to $323.00 per hectare.

In considering the navy bean - sugar beet production system, a mixed-integer linear programming model was formulated with 47 columns and 45 rows to select the most economical crop to produce, the agronomical requirements to apply, and the machinery set to use to maximize the total profit.

The results obtained from the navy bean - sugar beet production model indicated that under the present sugar beet yield level (50 ton/ha) and market price of (30 $/tonne), producing sugar beets was more profitable to the farmers. A farmer could make up to $214,066.00 profit from 200 ha of land which equals $1070.00 per hectare.

The results obtained from planting different percentages of navy beans and sugar beets applying different MILP models indicated the following:

1. By planting 150 ha sugar beets and 50 ha navy bean (75 percent sugar beets and 25 percent navy bean), a profit of $183,406.00 per year could be made which equals approximately $917.00 per hectare. The final results of this model were further improved by eliminating tractor 2 (T_2--59.7 kw) and operating row planter 2 (R_2--4.5 m) with tractor 4 (T_4--4.5m) instead. This production caused the total profit to jump up to $194,661.00 per year which equals $973.00 per hectare.
2. By planting 100 ha of sugar beets and 100 ha of navy bean (50 percent sugar beet and 50 percent navy bean), a farmer could make up to $174,966.00 per year which equals $875.00 per hectare.

3. By planting 50 ha of sugar beet and 150 ha of navy beans (25 percent sugar beet and 75 percent navy beans), a farmer could make up to $155,856.00 per year, which equals $779.00 per hectare.

Finally, it should be noted that each production system results included the following outputs:

1. The kind of crop(s) to be planted
2. The amount of seeds required
3. The amount of herbicide required
4. The amount of fertilizer required
5. The types and sizes of farm machinery contributing in the selected crop production system
6. The total net profit from the system.

7.2 Conclusions

According to the results obtained from applying mixed integer linear programming techniques on the navy bean, corn, and sugar beet production systems in Michigan, the following conclusions were drawn:

1. The MILP technique was a useful and successful tool in farm decision problems because of the following:
   a. The MILP model predicted the number and size of the machinery required for a given farm condition.

b. The selection of the number and size of machinery required was carried out according to the time limit for each field operation, the annual cost of using each type of implement and the labor cost in the best possible way to maximize the farmer's profit.

c. The MILP model provided a good estimate of seeds, fertilizers, herbicides, machinery, and labor costs, and the total annual profit of a crop production system.

2. The sensitivity analysis resulting from applying the MILP models were extremely useful because of the following:

   a. The sensitivity analysis indicated information about the amount of unused resources (slacks) and the price the farmer is willing to pay for each additional unit of resource (shadow prices).

   b. The sensitivity analysis provided information about the economic impact of forcing nonoptimal activities into the solution.

   c. The sensitivity analysis also indicated the range of values over which the objective function coefficient for a variable may change without changing the optimal solution.

7.2-1 Scope and Limitations

Some limitations were encountered during the study which can be presented as follow:

1. Data collected about yield of navy bean varieties (Swan Valley and Fleetwood) applying different production systems were not sufficient to build up an accurate decision about these varieties. Some figures were collected over a three-year period or two-year period, while others were collected over only a one-year period.
2. Because of poor weather conditions, resulting from excess rainfall during the 1981 harvest season, data collected did not reflect the expectations of these varieties.
3. The impact of having different crop rotation systems were not taken into consideration because of insufficient data.
4. One type of soil (medium textured) was taken into condition in the MILP models because of insufficient data and the limited capacity of the Harch and Black linear programming package (1975).
5. The Rotz et al. model (1981) about calculating the annual cost of using different farm machinery did not include all types of machinery so that some hand calculations were made to estimate the annual costs of using this machinery.

7.2-2 Future Research Needs

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

1. Since very little is known about navy bean varieties (Swan Valley and Fleetwood) applying different management systems, more agronomic study is needed on these two varieties covering different row spacing width applying direct and conventional harvest method.
2. Other alternative tillage systems should be tested with these varieties to see their economic impact on the farmer's profit.
3. Different crop rotation systems which include the new varieties with different production systems need to be considered in future studies.
4. The MILP models need to be modified to be operable in a microcomputer to make the use of this model easier.
5. The Harsh and Black package (1975) for the linear programming needs to be modified to handle more capacities of matrixes.
6. More machinery management data is required in the area of fuel consumption, draft, speeds, slippage, under various soil types and tillage systems.

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APPENDIX A

Mixed Integer Linear Programming Models For Solving Navy Bean Production Systems in Michigan

Mixed Integer Linear Programming Models

This appendix includes 18 mathematical models. Each one of these models contains the following information:

1. Objective function - which occupies the first line in an MILP matrix form. This function was set to be maximized. It should be noted that each value in the objective function represents the annual cost of using one unit of an activity.
2. Resources - which are presented on the left side of a matrix form to indicate the limited resources need to be allocted among the competing activities.
3. Amount of resource variable - are presented on the right side of a matrix form.
4. The amount of resource consumed by each unit of the corresponding activity represented by values occupy the main body of an MILP matrix form.

NAVY BEAN PRODUCTION MODEL

	FLEETWOOD			SWAN VALLEY			SEEDS	FERTI	HERBI	TRACTORS			M. B PLOWS			CH. PLOWS			SPREADER	F. CULTIV				R. PLANTERS			R. CULTIV			SPRAYERS			PULLERS			WINDROWERS			COMBINES				LABOR	SELLING	
	$/ha			$/ha				$/Kg		$/yr			$/yr			$/yr				$/yr				$/yr			$/yr			$/yr			$/yr			$/yr			$/yr				$/hr		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
	WD_1	WD_2	WC_3	SD_1	SD_2	SC_3	D_1	E_1	H_1	T_1	T_2	T_3	M_1	M_2	M_3	C_1	C_2	C_3	Z_1	F_1	F_2	F_3	F_4	R_1	R_2	R_3	V_1	V_2	V_3	S_1	S_2	S_3	B_1	B_2	B_3	W_1	W_2	W_3	H_1	H_2	H_3	H_4	LA	SB	
	40	40	40	40	40	40	0.88	-0.47	-4.15	6575	-10523	-15764	-1177	-1255	-1339	-460	-529	-561	663	303	-356	-411	-474	-1175	-1353	-1584	482	-583	-732	378	391	402	-283	-337	-397	-686	-772	-858	-10115	-12822	-10820	-13528	-6.0	0.44	
1 LAND ha	1	1	1	1	1	1																																							≤200
2 YIELD kg/ha	-1130	-1660	-1788	-1808	-2605	-1903																																						1	≤0
3 SEEDS kg/ha	67			67			-1																																						≤0
4 SEEDS kg/ha		45	45		45	45	-1																																						≤0
5 FERTILIZERS kg/ha	270	270	270	270	270	270		-1																																					≤0
5 HERBICIDES kg/ha	10.6	5.3	5.3	10.6	5.3	5.3			-1																																				≤[illegible]
7 PLOWING	1	1	1	1	1	1							-155	-187	-217	-200	-255	-270																											≤0
8 F. APPLICATION	1			1															-209																										≤0
9 F. CULTIVATION	1	1	1	1	1	1														-332	-393	-480	-579																						≤0
10 PLANTING	1	1	1	1	1	1																		-117	-174	-232																			≤0
11 R. CULTIVATION		1	1		1	1																					-165	-248	-330																≤0
12 SPRAYING	1	1	1	1	1	1																								-100	-135	-200													≤0
13 PULLING			1			1																											-113	-169	-225										≤0
14 WINDROWING			1			1																														-113	-169	-226							≤0
15 COMBINING			1			1																																			-209	-262			≤0
16 HARVESTING	1	1		1	1																																		-191	-239					≤0
17 TRACTOR 1 USAGE										-1000									116	81				138			164	109		274	200	135	170												≤[illegible]
18 TRACTOR 2 USAGE											-1000		174			135					66.6	55.5	43.2		91.7	68.7			82					113											≤0
19 TRACTOR 3 USAGE												-1000		145	124		105	100																	85										≤0
20 LABOR													174	45	124	135	105	100	116	81	66.6	55.5	43.2	138	91.7	68.7	164	109	82	274	200	135	170	113	85				160	128	92	73	-1		≤0
21 FORCING PLOWS															1	1	1	1																											=1
22 FORCING M_3															1																														≤1
23 FORCING C_1																1																													≤
24 FORCING C_2																	1																												≤1
25 FORCING C_3																		1																											≤1

	FLEETWOOD			SWAN VALLEY			SEEDS	FERTI.	HERBI.	TRACTORS			M. B PLOWS		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	WD_1	WD_2	WC_3	SD_1	SD_2	SC_3	D_1	E_1	H_1	T_1	T_2	T_3	M_1	M_2	M_3
	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
	40	40	40	40	40	40	66	.47	34.16	[illegible]	[illegible]	[illegible]	1177	1266	1330
26 FORCING F_0															
27 FORCING F_1															
28 FORCING F_2															
29 FORCING F_3															
30 FORCING F_4															
31 FORCING R_3															
32 FORCING V_a															
33 FORCING V_2															
34 FORCING V_3															
35 FORCING S_3															
36 FORCING H_3															
37 FORCING T_1										1					
38 FORCING T_2											1				

	CH PLOWS			SPREADER	F. CULTIV.				R. PLANTERS			R. CULTIV		
	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	C_1	C_2	C_3	Z_1	F_1	F_2	F_3	F_4	R_1	R_2	R_3	V_1	V_2	V_3
	−	−	−	−	−	−	−	−	−	−	−	−	−	−
	460	620	561	663	303	366	411	474	1178	1363	1664	482	582	732
26 FORCING F_0					1	1	1	1						
27 FORCING F_1					1									
28 FORCING F_2						1								
29 FORCING F_3							1							
30 FORCING F_4								1						
31 FORCING R_3											1			
32 FORCING V_a													1	1
33 FORCING V_2													1	
34 FORCING V_3														1
35 FORCING S_3														
36 FORCING H_3														
37 FORCING T_1														
38 FORCING T_2														

	SPRAYERS			PULLERS			WINDROWERS			COMBINES				LABOR	SELLING	
	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	
	S_1	S_2	S_3	B_1	B_2	B_3	W_1	W_2	W_3	H_1	H_2	H_3	H_4	LA	SB	
	−	−	−	−	−	−	−	−	−	−	−	−	−	−		
	378	301	408	283	337	307	686	772	660	[illegible]	[illegible]	[illegible]	[illegible]	6	44	
26 FORCING F_0																= 1
27 FORCING F_1																≤ 1
28 FORCING F_2																≤ 1
29 FORCING F_3																≤ 1
30 FORCING F_4																≤ 1
31 FORCING R_3																= 1
32 FORCING V_a																= 1
33 FORCING V_2																≤ 1
34 FORCING V_3																≤ 1
35 FORCING S_3			1													= 1
36 FORCING H_3												1				= 1
37 FORCING T_1																= 1
38 FORCING T_2																=

NAVY BEAN_CORN PRODUCTION MODEL

	CROPS		SEEDS	FERTI	HERBI	SEEDS	FERTI	HERBI	TRACTORS			CH. PLOWS			F. CULTIVATORS						R. PLANTERS						R. CULTIVATORS						SPRAYERS						HARVESTERS				SELLING		LABOR	
	$/ha		$/kg			$/kg			$/yr			$/yr			$/yr						$/yr						$/yr						$/yr						$/yr				$/kg	$/bu	$/hr	
	1 BE	2 CO	3 SB	4 FB	5 HB	6 SC	7 FC	8 HC	9 T_1	10 T_2	11 T_3	12 C_1	13 C_2	14 C_3	15 FB_1	16 FB_2	17 FB_3	18 FC_1	19 FC_2	20 FC_3	21 RB_1	22 RB_2	23 RB_3	24 RC_1	25 RC_2	26 RC_3	27 VB_1	28 VB_2	29 VB_3	30 VC_1	31 VC_2	32 VC_3	33 SB_1	34 SB_2	35 SB_3	36 SC_1	37 SC_2	38 SC_3	39 HB_1	40 HB_2	41 HC_1	42 HC_2	43 SB	44 SC	45 LA	
	-40	-40	-.88	-.47	[illegible]	-.18	-.33	-15	-6575	[illegible]	[illegible]	-480	-520	-661	-366	-411	-474	-366	-41	-474	-1178	-1363	-1604	-1178	-1363	-1584	-403	-603	-732	-402	-603	-732	-378	-391	-402	-378	-391	-402	[illegible]	[illegible]	[illegible]	[illegible]	.44	2.37	-6	
1 LAND ha	1																																													= 300
2 BE. YIELD kg/ha	-2000																																										1			≤ 0
3 CO. YIELD bu/ha		-230																																										1		≤ 0
4 BE SEEDS kg/ha	68		-1																																											≤ 0
5 CO. SEEDS kg/ha		14				-1																																								≤ 0
6 BE. FERTI. kg/ha	270			-1																																										≤ 0
7 CO. FERTI. kg/ha		310					-1																																							≤ 0
8 BE. HERBI. kg/ha	3.3				-1																																									≤ 0
9 CO. HERBI. kg/ha		3.4						-1																																						≤ 0
10 PLOWING	1	1										-300	-366	-370																																≤ 0
11 BE. F. CULTIV.	1														-303	-456	-570																													≤ 0
12 CO. F. CULTIV.		1																-306	-360	-432																										≤ 0
13 BE. PLANTING	1																				-117	-174	-232																							≤ 0
14 CO. PLANTING		1																						-117	-174	-232																				≤ 0
15 BE. R. CULTIV.	1																										-166	-248	-330																	≤ 0
16 CO. R. CULTIV.		1																												-170	-263	-361														≤ 0
17 BE. SPRAYING	1																																-100	-135	-200											≤ 0
18 CO. SPRAYING		1																																		-120	-160	-230								≤ 0
19 BE. HARVESTING	1																																						-101	-230						≤ 0
20 CO. HARVESTING		1																																							-101	-230				≤ 0
21 TRACTOR 1 USAGE									-1000												138			138			104	100		104	100		274	200	135	274	200	135								≤ 0
22 TRACTOR 2 USAGE										-1000		135			66.6	55.5	43.2	66.6	55.5	43.2		91.7	66.7		91.7	66.7			82			82														≤ 0
23 TRACTOR 3 USAGE											-1000		105	100																																≤ 0
24 LABOR USAGE												135	105	100	66.6	55.5	43.2	66.6	55.5	43.2	138	91.7	66.7	138	91.7	66.7	104	100	82	104	100	82	274	200	135	274	200	135	160	128	160	128			-1	≤ 0
25 FORCING C_o												1	1	1																																= 1

	CROPS		SEEDS	FERTI.	HERBI.	SEEDS	FERTI.	HERBI.	TRACTORS			CH. PLOWS			F. CULTIVATORS						R. PLANTERS						R. CULTIVATORS						SPRAYERS						HARVESTERS				SELLING		LABOR	
	$/ha		$/ha			$/ha			$/yr			$/yr			$/yr						$/yr						$/yr						$/yr						$/yr				$/kg	$/ha	$/hr	
	1 BE	2 CO	3 SB	4 FB	5 HB	6 SC	7 FC	8 HC	9 T_1	10 T_2	11 T_3	12 C_1	13 C_2	14 C_3	15 FB_2	16 FB_3	17 FB_4	18 FC_2	19 FC_3	20 FC_4	21 RB_1	22 RB_2	23 RB_3	24 RC_1	25 RC_2	26 RC_3	27 VB_1	28 VB_2	29 VB_3	30 VC_1	31 VC_2	32 VC_3	33 SB_1	34 SB_2	35 SB_3	36 SC_1	37 SC_2	38 SC_3	39 HB_1	40 HB_2	41 HC_1	42 HC_2	43 SB	44 SC	45 LA	
	-40	-40	-.88	-.47	-14.16	-18	-.33	-16	-8675	[illegible]	[illegible]	-460	-520	-561	-356	-411	-474	-356	-411	-474	-1178	-1363	-1684	-1178	-1363	-1684	-482	-583	-732	-482	-583	-732	-378	-381	-403	-378	-381	-403	[illegible]	[illegible]	[illegible]	[illegible]	.44	2.37	-8	
26 FORCING C_1												1																																		≤ 1
27 FORCING C_2													1																																	≤ 1
28 FORCING C_3														1																																≤ 1
29 FORCING FB_0															1	1	1																													$= 1$
30 FORCING FB_2															1																															≤ 1
31 FORCING FB_3																1																														≤ 1
32 FORCING FB_4																	1																													≤ 1
33 FORCING RB_3																							1																							$= 1$
34 FORCING VB_0																												1	1																	$= 1$
35 FORCING VB_2																												1																		≤ 1
36 FORCING VB_3																													1																	≤ 1
37 FORCING HB_2																																								1						$= 1$
38 FORCING T_1									1																																					$= 1$
39 FORCING T_2										1																																				$= 1$

75% NAVY BEAN_25% CORN PRODUCTION MODEL

	CROPS $/ha		SEEDS $/kg	FERTI	HERBI	SEEDS $/kg	FERTI	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			F. CULTIVATORS $/yr						R. PLANTERS $/yr						R. CULTIVATORS $/yr						SPRAYERS $/yr						HARVESTERS $/yr				SELLING $/kg	$/bu	LABOR $/hr	
	1 BE	2 CO	3 SB	4 FB	5 HB	6 SC	7 FC	8 HC	9 T_1	10 T	11 T_3	12 C_1	13 C_2	14 C_3	15 FB_2	16 FB_3	17 FB_4	18 FC_2	19 FC_3	20 FC_4	21 RB_1	22 RB_2	23 RB_3	24 RC_1	25 RC_2	26 RC_3	27 VB_1	28 VB_2	29 VB_3	30 VC_1	31 VC_2	32 VC_3	33 SB_1	34 SB_2	35 SB_3	36 SC_1	37 SC_2	38 SC_3	39 HB_1	40 HB_2	41 HC_1	42 HC_2	43 SB	44 SC	45 LA	
	-40	-40	-.56	-.47	-[illegible]	-.10	-.33	-.16	-6676	-[illegible]	-[illegible]	-460	-520	-561	-366	-411	-474	-366	-41	-474	-1176	-1362	-1604	-1176	-1362	-1604	-482	-563	-732	-482	-563	-732	-370	-301	-402	-378	-301	-402	-[illegible]	-[illegible]	-[illegible]	-[illegible]	.44	2.37	-6	
1 LAND ha.	1																																													= 300
2 BE. YIELD kg/ha	-3606																																										1			≤ 0
3 CO. YIELD bu/ha		-238																																										1		≤ 0
4 BE. SEEDS kg/ha	46		-1																																											≤ 0
5 CO. SEEDS kg/ha		14				-1																																								≤ 0
6 BE. FERTI. kg/ha	270			-1																																										≤ 0
7 CO. FERTI. kg/ha		310					-1																																							≤ 0
8 BE. HERBI. kg/ha	5.3				-1																																									≤ 0
9 CO. HERBI. kg/ha		3.4						-1																																						≤ 0
10 PLOWING	1	1										-200	-266	-270																																≤ 0
11 BE. F. CULTIV.	1														-303	-450	-570																													≤ 0
12 CO. F. CULTIV.		1																-306	-300	-432																										≤ 0
13 BE. PLANTING	1																				-117	-174	-232																							≤ 0
14 CO. PLANTING		1																						-117	-174	-232																				≤ 0
15 BE. R. CULTIV.	1																										-166	-240	-330																	≤ 0
16 CO. R. CULTIV.		1																												-176	-202	-301														≤ 0
17 BE. SPRAYING	1																																-100	-136	-200											≤ 0
18 CO. SPRAYING		1																																		-130	-100	-236								≤ 0
19 BE. HARVESTING	1																																						-101	-230						≤ 0
20 CO. HARVESTING		1																																							-101	-230				≤ 0
21 TRACTOR 1 USAGE									-1000												136			136			104	100		104	100		274	200	136	274	200	136								≤ 0
22 TRACTOR 2 USAGE										-1000		136			66.6	55.8	43.2	66.6	55.8	43.2		61.7	66.7		61.7	66.7			82			82														≤ 0
23 TRACTOR 3 USAGE											-1000		108	100																																≤ 0
24 LABOR USAGE												136	108	100	66.6	55.8	43.2	66.6	55.8	43.2	136	61.7	66.7	136	61.7	66.7	104	100	82	104	100	82	274	200	136	274	200	136	100	120	100	120			-1	≤ 0
25 BEAN LAND	1																																													= 100

	CROPS $/ha		SEEDS $/kg	FERTI	HERBI	SEEDS $/kg	FERTI	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			F. CULTIVATORS $/yr						R. PLANTERS $/yr						R. CULTIVATORS $/yr						SPRAYERS $/yr						HARVESTERS $/yr				SELLING $/kg $/ha		LABOR $/hr	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
	BE	CO	SB	FB	HB	SC	FC	HC	T_1	T_2	T_3	C_1	C_2	C_3	FB_2	FB_3	FB_4	FC_2	FC_3	FC_4	RB_1	RB_2	RB_3	RC_1	RC_2	RC_3	VB_1	VB_2	VB_3	VC_1	VC_2	VC_3	SB_1	SB_2	SB_3	SC_1	SC_2	SC_3	HB_1	HB_2	HC_1	HC_2	SB	SC	LA	
	-40	-40	-80	-47	-14.15	-18	-33	-15	-6675	[illegible]	[illegible]	-460	-520	-561	-356	-411	-474	-356	-411	-474	-1176	-1362	-1604	-1176	-1363	-1604	-402	-603	-732	-402	-603	-732	-378	-301	-402	-378	-301	-402	[illegible]	[illegible]	[illegible]	[illegible]	44	2.37	-8	
26 FORCING C_0												1	1	1																																= 1
27 FORCING C_1												1																																		≤ 1
28 FORCING C_2													1																																	≤ 1
29 FORCING C_3														1																																≤ 1
30 FORCING F_2															1			1																												= 1
31 FORCING R_2																						1			1																					= 1
32 FORCING V_1																											1			1																= 1
33 FORCING S_3																																			1			1								= 1
34 FORCING H_1																																							1		1					= 1
35 FORCING T_1									1																																					= 1
36 FORCING T_2										1																																				= 1
37																																														
38																																														
39																																														

50% NAVY BEAN_50% CORN PRODUCTION MODEL

	CROPS $/ha		SEEDS	FERTI $/kg	HERBI	SEEDS	FERTI $/kg	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			F. CULTIVATORS $/yr						R. PLANTERS $/yr						R. CULTIVATORS $/yr						SPRAYERS $/yr						HARVESTERS $/yr				SELLING $/kg $/bu		LABOR $/hr	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
	BE	CO	SB	FB	HB	SC	FC	HC	T_1	T	T_3	C_1	C_2	C_3	FB_1	FB_2	FB_3	FC_1	FC_2	FC_3	RB_1	RB_2	RB_3	RC_1	RC_2	RC_3	VB_1	VB_2	VB_3	VC_1	VC_2	VC_3	SB_1	SB_2	SB_3	SC_1	SC_2	SC_3	HB_1	HB_2	HC_1	HC_2	SB	SC	LA	
	-40	-40	-.80	-.47	-34.16	-.10	-.33	-15	[illegible]	[illegible]	[illegible]	-400	-520	-561	-366	-411	-474	-366	-41	-476	-1178	-1363	-1694	-1178	-1363	-1694	-483	-603	-732	-483	-603	-732	-378	-301	-402	-378	-301	-402	[illegible]	[illegible]	[illegible]	[illegible]	.44	3.37	-6	
1 LAND ha.	1																																													= 300
2 BE. YIELD kg/ha	-2000																																										1			≤ 0
3 CO. YIELD bu/ha		-238																																										1		≤ 0
4 BE. SEEDS kg/ha	48		-1																																											≤ 0
5 CO. SEEDS kg/ha		14				-1																																								≤ 0
6 BE. FERTI. kg/ha	270			-1																																										≤ 0
7 CO. FERTI. kg/ha		310					-1																																							≤ 0
8 BE. HERBI. kg/ha	5.3				-1																																									≤ 0
9 CO. HERBI. kg/ha		3.4						-1																																						≤ 0
10 PLOWING	1	1										-200	-286	-370																																≤ 0
11 BE. F. CULTIV.	1														-303	-456	-670																													≤ 0
12 CO. F. CULTIV.		1																-286	-360	-432																										≤ 0
13 BE. PLANTING	1																				-117	-174	-232																							≤ 0
14 CO. PLANTING		1																						-117	-174	-232																				≤ 0
15 BE. R. CULTIV.	1																										-165	-248	-330																	≤ 0
16 CO. R. CULTIV.		1																												-170	-263	-261														≤ 0
17 BE. SPRAYING	1																																-100	-135	-200											≤ 0
18 CO. SPRAYING		1																																		-120	-160	-236								≤ 0
19 BE. HARVESTING	1																																						-101	-230						≤ 0
20 CO. HARVESTING		1																																							-101	-230				≤ 0
21 TRACTOR 1 USAGE									-1000												138			138			104	100		104	100		274	200	136	274	200	136								≤ 0
22 TRACTOR 2 USAGE										-1000		136			66.6	66.6	43.2	66.6	66.6	43.2		91.7	66.7		91.7	66.7			82			82														≤ 0
23 TRACTOR 3 USAGE											-1000		106	100																																≤ 0
24 LABOR USAGE												136	106	100	66.6	66.6	43.2	66.6	66.6	43.2	138	91.7	66.7	138	91.7	66.7	104	100	82	104	100	82	274	200	136	274	200	136	160	128	160	128			-1	≤ 0
25 BEAN LAND	1																																													= 100

	CROPS $/ha		SEEDS $/kg	FERTI. $/kg	HERBI. $/kg	SEEDS $/kg	FERTI. $/kg	HERBI. $/kg	TRACTORS $/yr			CH. PLOWS $/yr			F. CULTIVATORS $/yr						R. PLANTERS $/yr						R. CULTIVATORS $/yr						SPRAYERS $/yr						HARVESTERS $/yr				SELLING $/kg	SELLING $/ha	LABOR $/hr	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
	BE	CO	SB	FB	HB	SC	FC	HC	T_1	T_2	T_3	C_1	C_2	C_3	FB_2	FB_3	FB_4	FC_2	FC_3	FC_4	PB_1	PB_2	PB_3	PC_1	PC_2	PC_3	VB_1	VB_2	VB_3	VC_1	VC_2	VC_3	SB_1	SB_2	SB_3	SC_1	SC_2	SC_3	HB_1	HB_2	HC_1	HC_2	SB	SC	LA	
	40	40	−.80	−.47	−14.30	−.10	−.33	−16	−[illegible]	−[illegible]	−[illegible]	−460	−530	−561	−366	−411	−474	−366	−411	−474	−1175	−1262	−1604	−1175	−[illegible]	−[illegible]	−482	−583	−732	−482	−583	−733	−378	−391	−402	−378	−391	−402	−[illegible]	−[illegible]	−[illegible]	−[illegible]	.44	2.37	−6	
26 FORCING C_0												1	1	1																																= 1
27 FORCING C_1												1																																		≤ 1
28 FORCING C_2													1																																	≤ 1
29 FORCING C_3														1																																≤ 1
30 FORCING F_2															1			1																												= 1
31 FORCING R_1																					1			1																						= 1
32 FORCING V_1																											1			1																= 1
33 FORCING S_1																																	1			1										= 1
34 FORCING H_1																																							1		1					= 1
35 FORCING T_1									1																																					= 1
36 FORCING T_2										1																																				= 1
37																																														
38																																														
39																																														

25% NAVY BEAN _ 75% CORN PRODUCTION MODEL

	CROPS $/ha		SEEDS	FERTI $/kg	HERBI	SEEDS	FERTI $/kg	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			F. CULTIVATORS $/yr						R. PLANTERS $/yr						R. CULTIVATORS $/yr						SPRAYERS $/yr						HARVESTERS $/yr				SELLING $/kg $/bu		LABOR $/hr	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
	BE	CO	SB	FB	HB	SC	FC	HC	T_1	T	T_2	C_1	C_2	C_3	FB_1	FB_2	FB_3	FC_1	FC_2	FC_3	RB_1	RB_2	RB_3	RC_1	RC_2	RC_3	VB_1	VB_2	VB_3	VC_1	VC_2	VC_3	SB_1	SB_2	SB_3	SC_1	SC_2	SC_3	HB_1	HB_2	HC_1	HC_2	SB	SC	LA	
	-40	-40	-.86	-.47	-34.16	-.10	-.33	-.16	-6675	[illegible]	[illegible]	-400	-520	-561	-356	-411	-474	-356	-41	-474	-1176	-1363	-1604	-1176	-1363	-1604	-462	-563	-732	-462	-563	-732	-378	-391	-462	-378	-391	-462	[illegible]	[illegible]	[illegible]	[illegible]	.44	2.37	-6	
1 LAND ha.	1																																													= 200
2 BE YIELD kg/ha	-2000																																										1			≤ 0
3 CO YIELD bu/ha		-228																																										1		≤ 0
4 BE SEEDS kg/ha	46		-1																																											≤ 0
5 CO SEEDS kg/ha		14				-1																																								≤ 0
6 BE FERTI. kg/ha	270			-1																																										≤ 0
7 CO FERTI. kg/ha		310					-1																																							≤ 0
8 BE HERBI kg/ha	6.3				-1																																									≤ 0
9 CO HERBI		3.4						-1																																						≤ 0
10 PLOWING	1	1										-300	-355	-370																																≤ 0
11 BE F. CULTIV.	1														-303	-450	-570																													≤ 0
12 CO F. CULTIV.		1																-306	-380	-432																										≤ 0
13 BE PLANTING	1																				-117	-174	-232																							≤ 0
14 CO PLANTING		1																						-117	-174	-232																				≤ 0
15 BE R. CULTIV.	1																										-166	-240	-330																	≤ 0
16 CO R. CULTIV.		1																												-178	-283	-381														≤ 0
17 BE SPRAYING	1																																-100	-136	-204											≤ 0
18 CO SPRAYING		1																																		-120	-160	-238								≤ 0
19 BE HARVESTING	1																																						-101	-230						≤ 0
20 CO HARVESTING		1																																							-101	-230				≤ 0
21 TRACTOR 1 USAGE									-1000												136			136			104	100		104	100		274	200	136	274	200	136								≤ 0
22 TRACTOR 2 USAGE										-1000		136			66.6	55.5	43.2	66.6	55.5	43.2		91.7	66.7		91.7	66.7			82			82														≤ 0
23 TRACTOR 3 USAGE											-1000		105	100																																≤ 0
24 LABOR USAGE												136	105	100	66.6	55.5	43.2	66.6	55.5	43.2	136	91.7	66.7	136	91.7	66.7	104	100	82	104	100	82	274	200	136	274	200	136	100	128	100	128			-.1	≤ 0
25 BEAN LAND	1																																													= 50

	CROPS $/ha		SEEDS $/kg	FERTI.	HERBI.	SEEDS $/kg	FERTI.	HERBI.	TRACTORS $/yr			CH. PLOWS $/yr			F. CULTIVATORS $/yr						R. PLANTERS $/yr						R. CULTIVATORS $/yr						SPRAYERS $/yr						HARVESTERS $/yr				SELLING $/kg	$/ha	LABOR $/hr	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	
	BE	CO	SB	FB	HB	SC	FC	HC	T_1	T_2	T_3	C_1	C_2	C_3	FB_2	FB_3	FB_4	FC_2	FC_3	FC_4	RB_1	RB_2	RB_3	RC_1	RC_2	RC_3	VB_1	VB_2	VB_3	VC_1	VC_2	VC_3	SB_1	SB_2	SB_3	SC_1	SC_2	SC_3	HB_1	HB_2	HC_1	HC_2	SB	SC	LA	
	-40	-40	-.88	-.47	-14.15	-.18	-.33	-.15	-6575	-10623	-15764	-460	-520	-561	-356	-411	-474	-356	-411	-474	-1176	-1363	-1664	-1176	-1363	-1664	-482	-583	-732	-482	-583	-732	-378	-391	-402	-378	-391	-402	-10116	-12822	-14780	-16190	.44	2.37	-6	
26 FORCING C_n												1	1	1																																= 1
27 FORCING C_1												1																																		≦ 1
28 FORCING C_2													1																																	≦ 1
29 FORCING C_3														1																																≦ 1
30 FORCING F_2															1			1																												= 1
31 FORCING R_2																						1			1																					= 1
32 FORCING V_1																											1			1																= 1
33 FORCING S_2																																		1			1									= 1
34 FORCING H_1																																							1		1					= 1
35 FORCING T_1									1																																					= 1
36 FORCING T_2										1																																				= 1

NAVY BEAN_SUGAR BEET PRODUCTION MODEL

	CROPS $/ha		SEEDS	FERTI	HERBI	SEEDS	FERTI	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			FIELD. CULTIVATORS $/yr						ROW PLANTERS $/yr						ROW CULTIVATIONS $/yr						SPRAYERS $/yr						HARVE. $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg	$/ton	LABOR	
			$/kg			$/kg																																										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
	B	S	SB	FB	HB	SS	FS	HS	T_1	T_2	T_4	C_1	C_2	C_3	FB_1	FB_2	FB_3	FS_1	FS_2	FS_3	RB_1	RB_2	RB_3	RS_1	RS_2	RS_3	VB_1	VB_2	VB_3	VS_1	VS_2	VS_3	SB_1	SB_2	SB_3	SS_1	SS_2	SS_3	H_1	H_2	P_1	P_2	L_1	L_2	BS	SBS	LA	
	-40	-40	-.08	-.47	-34.15	-46	-41	-20	-6678	[illegible]	[illegible]	-460	-520	-561	-366	-411	-474	-366	-411	-474	-1170	-1362	-1584	-1176	-1362	-1584	-483	-583	-733	-483	-583	-733	-370	-301	-403	-370	-301	-408	[illegible]	[illegible]	-1353	-1765	-3016	[illegible]	.44	30	-8	
1 LAND ha	1	1																																														≤300
2 B. YIELD kg/ha	-2000																																												1			≤0
3 S. YIELD ton/ha		-60																																												1		≤0
4 B. SEEDS kg/ha	45		-.1																																													≤0
5 S. SEEDS kg/ha		1.13				-.1																																										≤0
6 B. FERTILIZERS kg/ha	270			-.1																																												≤0
7 S. FERTILIZERS kg/ha		345					-.1																																									≤0
8 B. HERBICIDES kg/ha	3.3				-.1																																											≤0
9 S. HERBICIDES kg/ha		1.7						-.1																																								≤0
10 PLOWING	1	1										-200	-255	-270																																		≤0
11 B. F CULTIVATION	1														-303	-400	-570																															≤0
12 S. F CULTIVATION		1																-303	-400	-570																												≤0
13 B. PLANTING	1																				-117	-176	-233																									≤0
14 S. PLANTING		1																						-117	-174	-233																						≤0
15 B. R CULTIVATION	1																										-166	-240	-333																			≤0
16 S. R CULTIVATION		1																												-200	-300	-307																≤0
17 B. SPRAYING	1																																-100	-135	-200													≤0
18 S. SPRAYING		1																																		-120	-160	-330										≤0
19 B. HARVESTING	1																																						-101	-233								≤0
20 S. TOPPING		1																																							-161	-210						≤0
21 S. LIFTING		1																																									-161	-210				≤0
22 TRACTOR 1 USAGE									-3000												138			138			104	108		104	100		274	200	138	274	200	138			288	313						≤0
23 TRACTOR 2 USAGE										-3000		138			66.4	56.6	43.2	66.6	56.6	43.2		61.7	66.7		61.7	66.2			82			82																≤0
24 TRACTOR 4 USAGE											-3000		108	100																													288	313				≤0
25 LABOR USAGE												138	108	100	66.6	56.6	43.2	66.6	56.6	43.2	138	61.7	66.7	138	61.7	66.2	104	108	82	104	100	82	274	200	138	274	200	138	100	128	288	313	288	313			-1	≤0

	1 B	2 S	3 SB	4 FB	5 HB	6 SS	7 FS	8 HS	9 T_1	10 T_2	11 T_4	12 C_1	13 C_2	14 C_3	15 FB_2	16 FB_3	17 FB_4	18 FS_2	19 FS_3	20 FS_4	21 RB_1	22 RB_2	23 RB_3
	CROPS $/ha		SEEDS $/kg	FERTI $/kg	HERBI $/kg	SEEDS $/kg	FERTI $/kg	HERBI $/kg	TRACTORS $/yr			CH. PLOWS $/yr			FIELD CULTIVATORS $/yr						ROW PLANTERS $/yr		
	— 40	— 40	— .88	— .47	— 34.16	— 48	— .41	— 20	— [illegible]	— [illegible]	— [illegible]	— 406	— 520	— 661	— 388	— 411	— 474	— 388	— 411	— 474	— 1178	— 1363	— 1604
26 FORCING C_0												1	1	1									
27 FORCING C_1												1											
28 FORCING C_2													1										
29 FORCING C_3														1									
30 FORCING FS_0																		1	1	1			
31 FORCING FS_2																		1					
32 FORCING FS_3																			1				
33 FORCING FS_4																				1			
34 FORCING RS_3																							
35 FORCING VS_0																							
36 FORCING VS_1																							
37 FORCING VS_2																							
38 FORCING VS_3																							
39 FORCING SS_3																							
40 FORCING P_2																							
41 FORCING L_2																							
42 FORCING T_1									1														
43 FORCING T_2										1													
44 FORCING T_4											1												

	24 RS_1	25 RS_2	26 RS_3	27 VB_1	28 VB_2	29 VB_3	30 VS_1	31 VS_2	32 VS_3	33 SB_1	34 SB_2	35 SB_3	36 SS_1	37 SS_2	38 SS_3	39 H_1	40 H_2	41 P_1	42 P_2	43 L_1	44 L_2	45 BS	46 BBS	47 LA	
	ROW PLANTERS $/yr			ROW CULTIVATORS $/yr						SPRAYERS $/yr						HARVE. $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg	$/ton	LABOR	
	— 1178	— 1363	— 1604	— 482	— 603	— 732	— 482	— 603	— 732	— 378	— 391	— 402	— 378	— 391	— 402	— [illegible]	— [illegible]	— 1322	— 1782	— 2014	— 2886	.44	30	— 6	
26 FORCING C_0																									$= 1$
27 FORCING C_1																									≤ 1
28 FORCING C_2																									≤ 1
29 FORCING C_3																									≤ 1
30 FORCING FS_0																									$= 1$
31 FORCING FS_2																									≤ 1
32 FORCING FS_3																									≤ 1
33 FORCING FS_4																									≤ 1
34 FORCING RS_3			1																						$= 1$
35 FORCING VS_0							1	1	1																$= 1$
36 FORCING VS_1							1																		≤ 1
37 FORCING VS_2								1																	≤ 1
38 FORCING VS_3									1																≤ 1
39 FORCING SS_3															1										$= 1$
40 FORCING P_2																			1						$= 1$
41 FORCING L_2																					1				$= 1$
42 FORCING T_1																									$= 1$
43 FORCING T_2																									$= 1$
44 FORCING T_4																									$= 1$

25 % NAVY BEAN_ 75 %SUGER BEET PRODUCTION MODEL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
	CROPS		SEEDS	FERTI	HERBI	SEEDS	FERTI	HERBI	TRACTORS			CH. PLOWS			FIELD. CULTIVATORS						ROW PLANTERS						ROW CULTIVATIORS						SPRAYERS						HARVE.		TOPPERS		LIFTERS		SELLING		LABOR	
	$/ha		$/kg			$/kg			$/yr			$/yr			$/yr						$/yr						$/yr						$/yr						$/yr		$/yr		$/yr		$/kg	$/ton		
	B	S	SB	FB	HB	SS	FS	HS	T_1	T_2	T_4	C_1	C_2	C_3	FB_2	FB_3	FB_4	FS_2	FS_3	FS_4	RS_1	RS_2	RS_3	RS_1	RS_2	RS_3	VB_1	VB_2	VB_3	VS_1	VS_2	VS_3	SB_1	SB_2	SB_3	SS_1	SS_2	SS_3	H_1	H_2	P_1	P_2	L_1	L_2	BS	SBS	LA	
	-40	-40	-88	-47	-14.15	-45	-.41	-20	-6575	-10823	-21083	-460	-529	-561	-356	-411	-474	-356	-411	-474	-1178	-1353	-1804	-176	-1353	-1804	-482	-603	-732	-482	-603	-732	-378	-301	-402	-378	-301	-402	-8787	-10780	-1262	-1663	-2703	-3464	.44	30	-6	
1 LAND ha	1	1																																														≤200
2 B YIELD kg/ha	-2000																																												1			≤0
3 S YIELD ton/ha		-50																																												1		≤0
4 B SEEDS kg/ha	46		1																																													≤0
5 S. SEEDS kg/ha		1.13				1																																										≤0
6 B FERTILIZERS kg/ha	270			-.1																																												≤0
7 S FERTILIZERS kg/ha		345					-.1																																									≤0
8 B. HERBICIDES kg/ha	5.3				1																																											≤0
9 S. HERBICIDES kg/ha		1.7						1																																								≤0
10 PLOWING	1	1										-200	-255	-270																																		≤0
11 B F CULTIVATION	1														-303	-450	-570																															≤0
12 S F CULTIVATION		1																-303	-450	-570																												≤0
13 B PLANTING	1																				-117	-174	-232																									≤0
14 S. PLANTING		1																						-117	-174	-232																						≤0
15 B. R CULTIVATION	1																										-166	-249	-332																			≤0
16 S. R CULTIVATION		1																												-200	-299	-397																≤0
17 B. SPRAYING	1																																-100	-135	-200													≤0
18 S. SPRAYING		1																																		-120	-180	-236										≤0
19 B HARVESTING	1																																						-161	-232								≤0
20 S. TOPPING		1																																							-161	-216						≤0
21 S LIFTING		1																																									-161	-216				≤0
22 TRACTOR 1 USAGE									-1000												138			138			164	109		164	109		274	200	138	274	200	138			214	159						≤0
23 TRACTOR 2 USAGE										-1000		138			66.6	55.5	43.2	66.6	55.5	43.2		91.7	68.7		91.7	68.7			82			82																≤0
24 TRACTOR 4 USAGE											-1000		105	100																													214	159				≤0
25 LABOR USAGE												135	105	100	66.6	55.5	43.2	66.6	55.5	43.2	138	91.7	68.7	138	91.7	68.7	164	109	82	164	109	82	274	200	138	274	200	138	40	32	214	159	214	159			-.1	≤0

	CROPS $/ha		SEEDS $/kg	FERTI $/kg	HERBI $/kg	SEEDS $/kg	FERTI $/kg	HERBI $/kg	TRACTORS $/yr			CH PLOWS $/yr			FIELD CULTIVATORS $/yr						ROW PLANTERS $/yr						ROW CULTIVATORS $/yr						SPRAYERS $/yr						HARVE $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg	SELLING $/ton	LABOR	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
	B	S	SB	FB	HB	SS	FS	HS	T_1	T_2	T_4	C_1	C_2	C_3	FB_2	FB_3	FB_4	FS_2	FS_3	FS_4	RB_1	RB_2	RB_3	RS_1	RS_2	RS_3	VB_1	VB_2	VB_3	VS_1	VS_2	VS_3	SB_1	SB_2	SB_3	SS_1	SS_2	SS_3	H_1	H_2	P_1	P_2	L_1	L_2	BS	SBS	LA	
	−40	−40	−66	−47	−[illegible]	−45	−41	−20	−[illegible]	−[illegible]	−[illegible]	−406	−628	−661	−356	−411	−474	−356	−411	−474	−1176	−1363	−1604	−1176	−1363	−1604	−402	−603	−732	−402	−603	−732	−378	−301	−402	−378	−301	−402	−[illegible]	−[illegible]	−1322	−1703	−[illegible]	−[illegible]	44	30	−6	
26 [illegible]		1																																														=150
27 FORCING C[illegible]												1	1	1																																		=1
28 FORCING C_1												1																																				≤1
29 FORCING C_2													1																																			≤1
30 FORCING C_3														1																																		≤1
31 FORCING F_2															1			1																														=1
32 FORCING R_2																						1			1																							=1
33 FORCING V_1																											1			1																		=1
34 FORCING S_2																																		1			1											=1
35 FORCING H_1																																							1									=1
36 FORCING P_1																																									1							=1
37 FORCING L_1																																											1					=1
38 FORCING T_1									1																																							=1
39 FORCING T_4											1																																					=1
																																																=1

50 % NAVY BEAN_ 50 % SUGER BEET PRODUCTION MODEL

	CROPS $/ha		SEEDS $/kg	FERTI	HERBI	SEEDS $/kg	FERTI	HERBI	TRACTORS $/yr			CH PLOWS $/yr			FIELD CULTIVATORS $/yr						ROW PLANTERS $/yr		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	B	S	SB	FB	HB	SS	FS	HS	T_1	T_2	T_4	C_1	C_2	C_3	FB_2	FB_3	FB_4	FS_2	FS_3	FS_4	RS_1	RS_2	RS_3
	-40	-40	-88	-47	-14 15	-45	-41	-2 0	-6575	-10523	-21063	-460	-529	-561	-3 56	-411	-474	-356	-411	-474	-1175	-1353	-1584
1 LAND ha	1	1																					
2 B YIELD kg/ha	-2805																						
3 S YIELD ton/ha		-50																					
4 B SEEDS kg/ha	45		1																				
5 S SEEDS kg/ha		1 13				1																	
6 B FERTILIZERS kg/ha	270			1																			
7 S FERTILIZERS kg/ha		345					1																
8 B HERBICIDES kg/ha	5 3				1																		
9 S. HERBICIDES kg/ha		1 7						1															
10 PLOWING	1	1										-200	-255	-270									
11 B F CULTIVATION	1														-393	-480	-579						
12 S F CULTIVATION		1																-393	-480	-579			
13 B PLANTING	1																				-117	-174	-232
14 S PLANTING		1																					
15 B R CULTIVATION	1																						
16 S R CULTIVATION		1																					
17 B SPRAYING	1																						
18 S SPRAYING		1																					
19 B HARVESTING	1																						
20 S TOPPING		1																					
21 S LIFTING		1																					
22 TRACTOR 1 USAGE									-1000												138		
23 TRACTOR 2 USAGE										-1000		135			66 6	55.5	43 2	66 6	55 5	43 2		91 7	68 7
24 TRACTOR 4 USAGE											-1000		105	100									
25 LABOR USAGE												135	105	100	66 6	55 5	43 2	66 6	55 5	43 2	138	91 7	68 7

	ROW PLANTERS $/yr			ROW CULTIVATIONS $/yr						SPRAYERS $/yr						HARVE $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg	$/ton	LABOR	
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
	RS_1	RS_2	RS_3	VB_1	VB_2	VB_3	VS_1	VS_2	VS_3	SB_1	SB_2	SB_3	SS_1	SS_2	SS_3	H_1	H_2	P_1	P_2	L_1	L_2	BS	SBS	LA	
	-175	-1353	-1584	-482	-583	-732	-482	-583	-732	-378	-391	-402	-378	-391	-402	-9230	-11450	-1322	-1763	-2014	-30[illegible]	44	30	-6	
1 LAND ha																									≤ 200
2 B YIELD kg/ha																						1			≤ 0
3 S YIELD ton/ha																							1		≤ 0
4 B SEEDS kg/ha																									≤ 0
5 S SEEDS kg/ha																									≤ 0
6 B FERTILIZERS kg/ha																									≤ 0
7 S FERTILIZERS kg/ha																									≤ 0
8 B HERBICIDES kg/ha																									≤ 0
9 S. HERBICIDES kg/ha																									≤ 0
10 PLOWING																									≤ 0
11 B F CULTIVATION																									≤ 0
12 S F CULTIVATION																									≤ 0
13 B PLANTING																									≤ 0
14 S PLANTING	-117	-174	-232																						≤ 0
15 B R CULTIVATION				-165	-248	-332																			≤ 0
16 S R CULTIVATION							-200	-299	-387																≤ 0
17 B SPRAYING										-100	-135	-200													≤ 0
18 S SPRAYING													-120	-160	-236										≤ 0
19 B HARVESTING																-181	-232								≤ 0
20 S TOPPING																		-161	-216						≤ 0
21 S LIFTING																				-161	-216				≤ 0
22 TRACTOR 1 USAGE	138			164	109		164	109		274	200	135	274	200	135			142	106						≤ 0
23 TRACTOR 2 USAGE		91 7	68 7			8 2			8 2																≤ 0
24 TRACTOR 4 USAGE																				142	106				≤ 0
25 LABOR USAGE	138	91 7	68 7	164	109	82	164	109	82	274	200	135	274	200	135	80	84	142	106	142	108			1	≤ 0

	CROPS $/ha		SEEDS $/kg	FERTI	HERBI	SEEDS $/kg	FERTI	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			FIELD CULTIVATORS $/yr						ROW PLANTERS $/yr						ROW CULTIVATORS $/yr						SPRAYERS $/yr						HARVE $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg	$/ton	LABOR	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	
	B	S	SB	FB	HB	SS	FS	HS	T_1	T_2	T_4	C_1	C_2	C_3	FB_2	FB_3	FB_4	FS_2	FS_3	FS_4	RB_1	RB_2	RB_3	RS_1	RS_2	RS_3	VB_1	VB_2	VB_3	VS_1	VS_2	VS_3	SB_1	SB_2	SB_3	SS_1	SS_2	SS_3	H_1	H_2	P_1	P_2	L_1	L_2	BS	BBS	LA	
	−40	−40	−80	−47	−34.15	−45	−41	−20	−6676	[illegible]	[illegible]	−466	−520	−561	−366	−411	−474	−366	−411	−474	−1175	−1363	−1604	−1175	−1353	−1604	−482	−583	−732	−482	−583	−723	−378	−391	−402	−378	−391	−403	−1816	[illegible]	−1322	−1763	−2084	[illegible]	.44	38	−8	
26 BEET LAND		1																																														=100
27 FORCING C_0												1	1	1																																		=1
28 FORCING C_1												1																																				≤1
29 FORCING C_2													1																																			≤1
30 FORCING C_3														1																																		≤1
31 FORCING F_2															1			1																														=1
32 FORCING h_2																					1			1																								=1
33 FORCING V_1																											1			1																		=1
34 FORCING S_3																																	1			1												=1
35 FORCING H_1																																							1									=1
36 FORCING P_1																																									1							=1
37 FORCING L_1																																											1					=1
38 FORCING T_1									1																																							=1
39 FORCING T_4											1																																					=1
																																																=1

75 % NAVY BEAN _ 25 % SUGER BEET PRODUCTION MODEL

	CROPS $/ha		SEEDS $/kg	FERTI $/kg	HERBI $/kg	SEEDS $/kg	FERTI $/kg	HERBI $/kg	TRACTORS $/yr			CH PLOWS $/yr			FIELD CULTIVATORS $/yr						ROW PLANTERS $/yr		
	1 B	2 S	3 SB	4 FB	5 HB	6 SS	7 FS	8 HS	9 T_1	10 T_2	11 T_4	12 C_1	13 C_2	14 C_3	15 FB_2	16 FB_3	17 FB_4	18 FS_2	19 FS_3	20 FS_4	21 RS_1	22 RS_2	23 RS_3
	-40	-40	-88	-47	-14.15	-45	-41	-20	-6575	-10523	-21083	-460	-529	-561	-356	-411	-474	-356	-411	-474	-1175	-1353	-1584
1 LAND ha	1	1																					
2 B YIELD kg/ha	-2605																						
3 S YIELD ton/ha		-50																					
4 B SEEDS kg/ha	45		-1																				
5 S SEEDS kg/ha		1.13				-1																	
6 B FERTILIZERS kg/ha	270			-1																			
7 S FERTILIZERS kg/ha		345					-1																
8 B HERBICIDES kg/ha	5.3				-1																		
9 S HERBICIDES kg/ha		1.7						-1															
10 PLOWING	1	1										-200	-255	-270									
11 B F CULTIVATION	1														-393	-480	-579						
12 S F CULTIVATION		1																-393	-480	-579			
13 B PLANTING	1																				-117	-174	-232
14 S PLANTING		1																					
15 B R CULTIVATION	1																						
16 S R CULTIVATION		1																					
17 B SPRAYING	1																						
18 S SPRAYING		1																					
19 B HARVESTING	1																						
20 S TOPPING		1																					
21 S LIFTING		1																					
22 TRACTOR 1 USAGE									-1000												138		
23 TRACTOR 2 USAGE										-1000		135			66.6	55.5	43.2	66.6	55.5	43.2		91.7	68.7
24 TRACTOR 4 USAGE											-1000		105	100									
25 LABOR USAGE												135	105	100	66.6	55.5	43.2	66.6	55.5	43.2	138	91.7	68.7

	ROW PLANTERS $/yr			ROW CULTIVATORS $/yr						SPRAYERS $/yr						HARVE $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg $/ton		LABOR	
	24 RS_1	25 RS_2	26 RS_3	27 VB_1	28 VB_2	29 VB_3	30 VS_1	31 VS_2	32 VS_3	33 SB_1	34 SB_2	35 SB_3	36 SS_1	37 SS_2	38 SS_3	39 H_1	40 H_2	41 P_1	42 P_2	43 L_1	44 L_2	45 BS	46 SBS	47 LA	
	-1175	-1353	-1584	-482	-583	-732	-482	-583	-732	-378	-391	-402	-378	-391	-402	-9674	-12137	-1026	-1328	-2263	-2940	-44	-30	-6	
1 LAND ha																									≤ 200
2 B YIELD kg/ha																						1			≤ 0
3 S YIELD ton/ha																							1		≤ 0
4 B SEEDS kg/ha																									≤ 0
5 S SEEDS kg/ha																									≤ 0
6 B FERTILIZERS kg/ha																									≤ 0
7 S FERTILIZERS kg/ha																									≤ 0
8 B HERBICIDES kg/ha																									≤ 0
9 S HERBICIDES kg/ha																									≤ 0
10 PLOWING																									≤ 0
11 B F CULTIVATION																									≤ 0
12 S F CULTIVATION																									≤ 0
13 B PLANTING																									≤ 0
14 S PLANTING	-117	-174	-232																						≤ 0
15 B R CULTIVATION				-165	-248	-332																			≤ 0
16 S R CULTIVATION							-200	-299	-397																≤ 0
17 B SPRAYING										-100	-135	-200													≤ 0
18 S SPRAYING													-120	-160	-238										≤ 0
19 B HARVESTING																-191	-232								≤ 0
20 S TOPPING																		-161	-216						≤ 0
21 S LIFTING																				-161	-216				≤ 0
22 TRACTOR 1 USAGE	138			164	109		164	109		274	200	135	274	200	135			71	53						≤ 0
23 TRACTOR 2 USAGE		91.7	68.7			8.2			8.2																≤ 0
24 TRACTOR 4 USAGE																				71	53				≤ 0
25 LABOR USAGE	138	91.7	68.7	164	109	8.2	164	109	8.2	274	200	135	274	200	135	120	96	71	53	71	53			-1	≤ 0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	46	46	47	
	CROPS $/ha		SEEDS $/kg	FERTI	HERBI	SEEDS $/kg	FERTI	HERBI	TRACTORS $/yr			CH. PLOWS $/yr			FIELD CULTIVATORS $/yr						ROW PLANTERS $/yr						ROW CULTIVATORS $/yr						SPRAYERS $/yr						HARVE. $/yr		TOPPERS $/yr		LIFTERS $/yr		SELLING $/kg	$/ton	LABOR	
	B	S	SB	FB	HB	SS	FS	HS	T_1	T_2	T_4	C_1	C_2	C_3	FB_2	FB_3	FB_4	FS_2	FS_3	FS_4	RB_1	RB_2	RB_3	RS_1	RS_2	RS_3	VB_1	VB_2	VB_3	VS_1	VS_2	VS_3	SB_1	SB_2	SB_3	SS_1	SS_2	SS_3	H_1	H_2	P_1	P_2	L_1	L_2	BS	SBS	LA	
	−40	−40	−88	−47	−1415	−45	−41	−20	−8575	−10623	−21062	−460	−520	−561	−356	−411	−474	−356	−411	−474	−1176	−1363	−1684	−1176	−1363	−1684	−402	−583	−732	−402	−583	−732	−378	−391	−402	−378	−391	−402	−10118	−12822	−1322	−1763	−2914	−2895	44	30	−6	
26 BEET LAND		1																																														
27 FORCING C_n												1	1	1																																		=60
28 FORCING C_1												1																																				=1
29 FORCING C_2													1																																			≤1
30 FORCING C_3														1																																		≤1
31 FORCING F_2															1			1																														≤1
32 FORCING R_2																						1			1																							=1
33 FORCING V_1																											1			1																		=1
34 FORCING S_3																																			1			1										=1
35 FORCING H_1																																							1									=1
36 FORCING P_1																																									1							=1
37 FORCING L_1																																											1					=1
38 FORCING T_1									1																																							=1
39 FORCING T_4											1																																					=1
																																																=1
																																																=1

APPENDIX B

The Computer Results of the Mixed Integer Linear Programming Models

The Computer Results of the MILP Models

This appendix includes the computer results of the mixed integer linear programming models. Each computer output contains the following information:

1. The objective function - which represent the total profit $/year can be made from 200 ha of land.
2. Activities in solution - which represent the kind of crop to be planted, size of land, agronomic requirements (seeds, fertilizer, herbicides), the size and the number of machines to be used in the production system and the number of hours required to accomplish the field activities.
3. Shadow prices - which represent the value of one additional unit of the resource associated with linear programming.
4. Slacks - which represent the amount of unused resources.
5. The cost of forcing nonoptimal ativities into optimal solution.
6. Range of optimality - which represent the range of values over which the objective function coefficient for a variable may change without changing the optimal solution.

The Optimal Solution of the Navy Bean Production Model

```
OPTIMAL SOLUTION (     40)

OBJECTIVE FUNCTION=          135[illegible]01.9000

ACTIVITIES IN SOLUTION
 ACTIVITY     5    IS      200.0000
 ACTIVITY     7    IS     9000.0000
 ACTIVITY     8    IS    54000.0000
 ACTIVITY     9    IS     1960.0000
 ACTIVITY    10    IS        1.0000
 ACTIVITY    11    IS        1.0000
 ACTIVITY    12    IS         .0000
 ACTIVITY    16    IS        1.0000
 ACTIVITY    18    IS         .0000
 ACTIVITY    19    IS         .0000
 ACTIVITY    21    IS         .0000
 ACTIVITY    22    IS        1.0000
 ACTIVITY    23    IS      604.2000
 ACTIVITY    26    IS        1.0000
 ACTIVITY    29    IS        1.0000
 ACTIVITY    30    IS         .0000
 ACTIVITY    31    IS        1.0000
 ACTIVITY    33    IS         .0000
 ACTIVITY    39    IS        1.0000
 ACTIVITY    42    IS   521000.0000


SHADOW PRICES AND SLACKS
 ROW    1   PRICE      643.8776   EXCESS       0.0000
 ROW    2   PRICE         .4400   EXCESS       0.0000
 ROW    3   PRICE        0.0000   EXCESS    9000.0000
 ROW    4   PRICE         .8800   EXCESS       0.0000
 ROW    5   PRICE         .4700   EXCESS       0.0000
 ROW    6   PRICE       14.1500   EXCESS       0.0000
 ROW    7   PRICE       10.1385   EXCESS       0.0000
 ROW    8   PRICE        6.5024   EXCESS       0.0000
 ROW    9   PRICE        0.0000   EXCESS     375.0000
 ROW   10   PRICE        0.0000   EXCESS      32.0000
 ROW   11   PRICE        0.0000   EXCESS     130.0000
 ROW   12   PRICE       10.6899   EXCESS       0.0000
 ROW   13   PRICE        6.0059   EXCESS       0.0000
 ROW   14   PRICE        0.0000   EXCESS       0.0000
 ROW   15   PRICE        0.0000   EXCESS       0.0000
 ROW   16   PRICE        0.0000   EXCESS      39.0000
 ROW   17   PRICE        0.0000   EXCESS     865.0000
 ROW   18   PRICE        0.0000   EXCESS     656.8000
 ROW   19   PRICE       15.7640   EXCESS       0.0000
 ROW   20   PRICE     -228.8978   EXCESS       0.0000
 ROW   21   PRICE        0.0000   EXCESS       1.0000
 ROW   22   PRICE      966.6015   EXCESS       0.0000
 ROW   23   PRICE        0.0000   EXCESS       1.0000
 ROW   24   PRICE     -810.5000   EXCESS       0.0000
 ROW   25   PRICE        0.0000   EXCESS       1.0000
 ROW   26   PRICE        0.0000   EXCESS       1.0000
 ROW   27   PRICE        3.5000   EXCESS       0.0000
 ROW   28   PRICE      963.7778   EXCESS       0.0000
 ROW   29   PRICE    -1996.2000   EXCESS       0.0000
 ROW   30   PRICE    -1237.0000   EXCESS       0.0000
 ROW   31   PRICE        0.0000   EXCESS       1.0000
 ROW   32   PRICE       17.0000   EXCESS       0.0000
 ROW   33   PRICE   -13590.0000   EXCESS       0.0000
 ROW   34   PRICE    -6575.0000   EXCESS       0.0000
 ROW   35   PRICE   -10523.0000   EXCESS       0.0000
 ROW   36   PRICE        6.0000   EXCESS       0.0000
```

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	1	IS	[illegible].8574
ACTIVITY	2	IS	415.8000
ACTIVITY	3	IS	355.4859
ACTIVITY	4	IS	392.5774
ACTIVITY	6	IS	314.8658
ACTIVITY	13	IS	649.5296
ACTIVITY	14	IS	2514.8770
ACTIVITY	15	IS	1608.7757
ACTIVITY	20	IS	31.4000
ACTIVITY	24	IS	2003.0000
ACTIVITY	25	IS	1903.2000
ACTIVITY	27	IS	1466.0000
ACTIVITY	32	IS	624.3314
ACTIVITY	34	IS	895.6086
ACTIVITY	35	IS	686.0000
ACTIVITY	36	IS	772.0000
ACTIVITY	37	IS	858.0000
ACTIVITY	39	IS	11075.0000
ACTIVITY	40	IS	11730.0000
ACTIVITY	41	IS	14296.0000

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY LOWER BOUND	PRICE	ACTIVITY UPPER BOUND	PRICE
ACTIVITY	5	6	-385.4171	0	3959960.0000
ACTIVITY	7	4	-9.2599	46	-.0000
ACTIVITY	8	43	-3.2651	47	0.0000
ACTIVITY	9	43	-156.5437	48	0.0000
ACTIVITY	10	43	-1124629.9247	28	-5173.6485
ACTIVITY	11	28	-11057.0565	16	-9779.6011
ACTIVITY	12	16	-16767.5835	61	-.0000
ACTIVITY	18	16	-691.4665	49	2329.3200
ACTIVITY	22	20	-826.9765	51	2643.6800
ACTIVITY	23	43	-257.4955	28	-4.3848
ACTIVITY	26	25	-2464.9200	52	1982.7600
ACTIVITY	29	25	-804.0976	53	2232.6050
ACTIVITY	31	30	-1177.3750	54	1697.6250
ACTIVITY	39	3[illegible]	-12587.6911	58	816.0000
ACTIVITY	41	40	-13669.0000	57	576.0000
ACTIVITY	42	43	.1503	0	9000000.4400

The Optimal Solution of Navy Bean - Corn Production Model

OBJECTIVE FUNCTION= 135743.9000

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	200.0000
ACTIVITY	3	IS	9000.0000
ACTIVITY	4	IS	54000.0000
ACTIVITY	5	IS	1060.0000
ACTIVITY	6	IS	.0000
ACTIVITY	7	IS	.0000
ACTIVITY	8	IS	.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	1.0000
ACTIVITY	11	IS	.0000
ACTIVITY	12	IS	1.0000
ACTIVITY	14	IS	.0000
ACTIVITY	16	IS	.0000
ACTIVITY	17	IS	1.0000
ACTIVITY	23	IS	1.0000
ACTIVITY	26	IS	.0000
ACTIVITY	29	IS	1.0000
ACTIVITY	32	IS	.0000
ACTIVITY	35	IS	1.0000
ACTIVITY	38	IS	.0000
ACTIVITY	40	IS	1.0000
ACTIVITY	41	IS	.0000
ACTIVITY	43	IS	521000.0000
ACTIVITY	44	IS	.0000
ACTIVITY	45	IS	604.2000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	848.3065	EXCESS	0.0000
ROW	2	PRICE	.4400	EXCESS	0.0000
ROW	3	PRICE	2.3700	EXCESS	0.0000
ROW	4	PRICE	.6600	EXCESS	0.0000
ROW	5	PRICE	.1900	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.3300	EXCESS	0.0000
ROW	8	PRICE	14.1500	EXCESS	0.0000
ROW	9	PRICE	15.0000	EXCESS	0.0000
ROW	10	PRICE	10.1395	EXCESS	0.0000
ROW	11	PRICE	0.0000	EXCESS	379.0000
ROW	12	PRICE	0.0000	EXCESS	.0000
ROW	13	PRICE	0.0000	EXCESS	32.0000
ROW	14	PRICE	8.6043	EXCESS	0.0000
ROW	15	PRICE	0.0000	EXCESS	130.0000
ROW	16	PRICE	3.4872	EXCESS	0.0000
ROW	17	PRICE	6.3500	EXCESS	0.0000
ROW	18	PRICE	5.1356	EXCESS	0.0000
ROW	19	PRICE	0.0000	EXCESS	39.0000
ROW	20	PRICE	82.3037	EXCESS	0.0000
ROW	21	PRICE	0.0000	EXCESS	365.0000
ROW	22	PRICE	0.0000	EXCESS	659.0000
ROW	23	PRICE	15.7640	EXCESS	0.0000
ROW	24	PRICE	6.0000	EXCESS	0.0000
ROW	25	PRICE	-228.8972	EXCESS	0.0000
ROW	26	PRICE	986.5015	EXCESS	0.0000
ROW	27	PRICE	0.0000	EXCESS	1.0000
ROW	28	PRICE	-210.5000	EXCESS	0.0000
ROW	29	PRICE	0.0000	EXCESS	1.0000
ROW	30	PRICE	0.0000	EXCESS	1.0000
ROW	31	PRICE	3.5000	EXCESS	0.0000
ROW	32	PRICE	-1996.2000	EXCESS	0.0000
ROW	33	PRICE	-1237.0000	EXCESS	0.0000
ROW	34	PRICE	0.0000	EXCESS	1.0000
ROW	35	PRICE	13.0000	EXCESS	1.0000
ROW	36	PRICE	-13590.0000	EXCESS	0.0000
ROW	37	PRICE	-6575.0000	EXCESS	0.0000
ROW	38	PRICE	-10523.0000	EXCESS	0.0000

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	2	IS	589.9357
ACTIVITY	15	IS	211.4000
ACTIVITY	18	IS	842.0000
ACTIVITY	19	IS	810.6000
ACTIVITY	20	IS	907.0000
ACTIVITY	21	IS	2003.0000
ACTIVITY	22	IS	1903.2000
ACTIVITY	24	IS	996.2857
ACTIVITY	25	IS	406.2500
ACTIVITY	27	IS	1466.0000
ACTIVITY	30	IS	852.2564
ACTIVITY	31	IS	319.9716
ACTIVITY	33	IS	1416.0000
ACTIVITY	34	IS	772.9000
ACTIVITY	36	IS	1405.7268
ACTIVITY	37	IS	769.3051
ACTIVITY	39	IS	11075.0000
ACTIVITY	42	IS	287.4241

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY LOWER	PRICE BOUND	ACTIVITY UPPER	PRICE BOUND
ACTIVITY	1	44	-560.7445	0	8399960.000
ACTIVITY	2	0	-9000040.0000	44	480.744
ACTIVITY	3	44	-12.4521	49	0.000
ACTIVITY	4	44	-2.3987	51	0.000
ACTIVITY	5	44	-112.4037	53	0.000
ACTIVITY	6	0	-9000000.1300	50	0.000
ACTIVITY	7	0	-9000000.3300	52	0.000
ACTIVITY	8	0	-9000015.0000	54	0.000
ACTIVITY	9	46	-1142515.2707	28	-3039.692
ACTIVITY	10	28	-15775.1974	12	-5612.620
ACTIVITY	11	12	-24713.1675	68	-.000
ACTIVITY	14	13	-803.3624	55	2176.400
ACTIVITY	17	16	-906.1381	56	917.026
ACTIVITY	20	19	-896.6917	57	917.026
ACTIVITY	23	22	-2689.0820	58	1135.130
ACTIVITY	26	25	-2689.0820	59	1135.130
ACTIVITY	29	28	-1244.7622	60	1354.366
ACTIVITY	32	31	-1252.4901	61	1354.366
ACTIVITY	35	34	-2607.5602	62	1697.625
ACTIVITY	38	37	-2558.7250	63	1697.625
ACTIVITY	40	39	-13390.2461	64	768.000
ACTIVITY	41	42	-14969.6987	65	760.000
ACTIVITY	43	44	.2401	0	9000000.44[illegible]
ACTIVITY	45	42	-9.9824	39	-2.2[illegible][illegible]

The Optimal Solution of 75 Percent Navy Bean - 25 Percent Corn Production Model

START L. P. SOLVE

OPTIMAL SOLUTION (32)

OBJECTIVE FUNCTION= 112359.2661

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	150.0000
ACTIVITY	2	IS	50.0000
ACTIVITY	3	IS	6750.0000
ACTIVITY	4	IS	40500.0000
ACTIVITY	5	IS	755.0000
ACTIVITY	6	IS	700.0000
ACTIVITY	7	IS	15500.0000
ACTIVITY	8	IS	170.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	1.0000
ACTIVITY	11	IS	.0000
ACTIVITY	12	IS	1.0000
ACTIVITY	14	IS	.0000
ACTIVITY	15	IS	.3817
ACTIVITY	18	IS	.6183
ACTIVITY	22	IS	.8553
ACTIVITY	25	IS	.1437
ACTIVITY	27	IS	.8539
ACTIVITY	30	IS	.1452
ACTIVITY	35	IS	.6941
ACTIVITY	38	IS	.1059
ACTIVITY	39	IS	.8227
ACTIVITY	41	IS	.1773
ACTIVITY	43	IS	390750.0000
ACTIVITY	44	IS	11900.0000
ACTIVITY	45	IS	766.7000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	341.6299	EXCESS	0.0000
ROW	2	PRICE	.4400	EXCESS	0.0000
ROW	3	PRICE	2.3700	EXCESS	0.0000
ROW	4	PRICE	.8800	EXCESS	0.0000
ROW	5	PRICE	.1800	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.3300	EXCESS	0.0000
ROW	8	PRICE	14.1500	EXCESS	0.0000
ROW	9	PRICE	15.0000	EXCESS	0.0000
ROW	10	PRICE	10.1385	EXCESS	0.0000
ROW	11	PRICE	.4580	EXCESS	0.0000
ROW	12	PRICE	0.0000	EXCESS	132.4045
ROW	13	PRICE	0.0000	EXCESS	14[illegible].0000
ROW	14	PRICE	0.0000	EXCESS	0.0000
ROW	15	PRICE	0.0000	EXCESS	131.7544
ROW	16	PRICE	0.0000	EXCESS	0.0000
ROW	17	PRICE	0.0000	EXCESS	207.6271
ROW	18	PRICE	0.0000	EXCESS	0.0000
ROW	19	PRICE	0.0000	EXCESS	82.0000
ROW	20	PRICE	16.4716	EXCESS	0.0000
ROW	21	PRICE	[illegible]0.0000	EXCESS	620.0000
ROW	22	PRICE	0.0000	EXCESS	773.3000
ROW	23	PRICE	15.7640	EXCESS	0.0000
ROW	24	PRICE	6.0000	EXCESS	0.0000
ROW	25	PRICE	512.4786	EXCESS	0.0000
ROW	26	PRICE	757.7037	EXCESS	0.0000
ROW	27	PRICE	0.0000	EXCESS	.0000
ROW	28	PRICE	0.0000	EXCESS	1.0000
ROW	29	PRICE	-842.0000	EXCESS	0.0000
ROW	30	PRICE	-1903.2000	EXCESS	0.0000
ROW	31	PRICE	-1456.0000	EXCESS	0.0000
ROW	32	PRICE	-1212.0000	EXCESS	0.0000
ROW	33	PRICE	-11075.0000	EXCESS	0.0000
ROW	34	PRICE	-6575.0000	EXCESS	0.0000
ROW	35	PRICE	-10523.0000	EXCESS	0.0000

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	13	IS	986.6015
ACTIVITY	16	IS	590.7527
ACTIVITY	17	IS	541.8092
ACTIVITY	19	IS	810.6000
ACTIVITY	20	IS	807.0000
ACTIVITY	21	IS	2003.0000
ACTIVITY	23	IS	1996.2000
ACTIVITY	24	IS	2003.0000
ACTIVITY	26	IS	1996.2000
ACTIVITY	28	IS	1237.0000
ACTIVITY	29	IS	1224.0000
ACTIVITY	31	IS	1237.0000
ACTIVITY	32	IS	1224.0000
ACTIVITY	33	IS	2022.0000
ACTIVITY	34	IS	1591.0000
ACTIVITY	36	IS	2022.0000
ACTIVITY	37	IS	1591.0000
ACTIVITY	40	IS	13590.0000
ACTIVITY	42	IS	16021.2801

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY	PRICE	ACTIVITY	PRICE
		LOWER BOUND		UPPER BOUND	
ACTIVITY	1	70	-552.4786	0	8999960.0000
ACTIVITY	2	46	-381.6299	70	472.4786
ACTIVITY	3	70	-12.2634	49	0.0000
ACTIVITY	4	70	-2.3581	51	0.0000
ACTIVITY	5	70	-110.8441	53	0.0000
ACTIVITY	6	46	-24.5821	50	0.0000
ACTIVITY	7	46	-1.4320	52	0.0000
ACTIVITY	8	46	-115.4794	54	0.0000
ACTIVITY	9	0	-9006575.0000	79	0.0000
ACTIVITY	10	0	-9010523.0000	80	0.0000
ACTIVITY	11	46	-935164.5957	71	-5535.0000
ACTIVITY	12	71	-1217.7037	0	8999540.0000
ACTIVITY	14	13	-5404.3164	71	461.9000
ACTIVITY	15	17	-903.7565	56	-356.0000
ACTIVITY	18	56	-536.0000	17	11.7565
ACTIVITY	22	70	-179695.5583	75	550.2000
ACTIVITY	25	24	-4331.8205	73	179989.5583
ACTIVITY	27	70	-175749.6867	32	710.6154
ACTIVITY	30	32	-1674.6154	73	174795.6867
ACTIVITY	35	70	-242291.9067	77	810.0000
ACTIVITY	38	37	-2748.7250	73	241487.9067
ACTIVITY	39	65	-14760.0000	78	960.0000
ACTIVITY	41	42	-33663.7639	65	-10115.0000
ACTIVITY	43	70	.2433	0	9000000.44[illegible]
ACTIVITY	44	46	.9346	73	4.5233
ACTIVITY	45	71	-15.4365	69	0.0000

The Optimal Solution of the 50 Percent Navy Bean - 50 Percent Corn Production Model

```
START L. P. SOLVE

OPTIMAL SOLUTION (     35)

OBJECTIVE FUNCTION=            85025.5354

ACTIVITIES IN SOLUTION
 ACTIVITY     1     IS       100.0000
 ACTIVITY     2     IS       100.0000
 ACTIVITY     3     IS      4500.0000
 ACTIVITY     4     IS     27000.0000
 ACTIVITY     5     IS       530.0000
 ACTIVITY     6     IS      1400.0000
 ACTIVITY     7     IS     31000.0000
 ACTIVITY     8     IS       340.0000
 ACTIVITY     9     IS         1.0000
 ACTIVITY    10     IS         1.0000
 ACTIVITY    11     IS          .0000
 ACTIVITY    12     IS         1.0000
 ACTIVITY    14     IS          .0000
 ACTIVITY    15     IS          .2545
 ACTIVITY    18     IS          .7455
 ACTIVITY    21     IS          .5726
 ACTIVITY    24     IS          .4274
 ACTIVITY    27     IS          .7076
 ACTIVITY    30     IS          .2924
 ACTIVITY    33     IS          .5833
 ACTIVITY    36     IS          .4167
 ACTIVITY    39     IS          .6454
 ACTIVITY    41     IS          .3546
 ACTIVITY    43     IS    260500.0000
 ACTIVITY    44     IS     23800.0000
 ACTIVITY    45     IS       952.0000


SHADOW PRICES AND SLACKS
 ROW     1     PRICE          341.6299     EXCESS          0.0000
 ROW     2     PRICE             .4400     EXCESS          0.0000
 ROW     3     PRICE            2.3700     EXCESS          0.0000
 ROW     4     PRICE             .8800     EXCESS          0.0000
 ROW     5     PRICE             .1600     EXCESS          0.0000
 ROW     6     PRICE             .4700     EXCESS          0.0000
 ROW     7     PRICE             .3300     EXCESS          0.0000
 ROW     8     PRICE           14.1500     EXCESS          0.0000
 ROW     9     PRICE           15.0000     EXCESS          0.0000
 ROW    10     PRICE           10.1385     EXCESS          0.0000
 ROW    11     PRICE             .4580     EXCESS          0.0000
 ROW    12     PRICE            0.0000     EXCESS        119.9364
 ROW    13     PRICE            0.0000     EXCESS         34.0000
 ROW    14     PRICE            0.0000     EXCESS          0.0000
 ROW    15     PRICE            0.0000     EXCESS        133.5088
 ROW    16     PRICE            0.0000     EXCESS          0.0000
 ROW    17     PRICE            0.0000     EXCESS         16.6667
 ROW    18     PRICE            0.0000     EXCESS          0.0000
 ROW    19     PRICE            0.0000     EXCESS         92.0000
 ROW    20     PRICE           16.4716     EXCESS          0.0000
 ROW    21     PRICE            0.0000     EXCESS        343.0000
 ROW    22     PRICE            0.0000     EXCESS        865.0000
 ROW    23     PRICE           15.7540     EXCESS          0.0000
 ROW    24     PRICE            6.0000     EXCESS          0.0000
 ROW    25     PRICE          512.4796     EXCESS          0.0000
 ROW    26     PRICE          757.7037     EXCESS          0.0000
 ROW    27     PRICE            0.0000     EXCESS           .0000
 ROW    28     PRICE            0.0000     EXCESS          1.0000
 ROW    29     PRICE         -842.0000     EXCESS          0.0000
 ROW    30     PRICE        -2000.0000     EXCESS          0.0000
 ROW    31     PRICE        -1466.0000     EXCESS          0.0000
 ROW    32     PRICE        -2022.0000     EXCESS          0.0000
 ROW    33     PRICE       -11075.0000     EXCESS          0.0000
 ROW    34     PRICE        -6575.0000     EXCESS          0.0000
 ROW    35     PRICE       -10523.0000     EXCESS          0.0000
```

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	13	IS	986.6015
ACTIVITY	16	IS	590.7527
ACTIVITY	17	IS	541.8092
ACTIVITY	19	IS	810.6000
ACTIVITY	20	IS	807.0000
ACTIVITY	22	IS	1903.2000
ACTIVITY	23	IS	1996.2000
ACTIVITY	25	IS	1903.2000
ACTIVITY	26	IS	1996.2000
ACTIVITY	28	IS	1237.0000
ACTIVITY	29	IS	1224.0000
ACTIVITY	31	IS	1237.0000
ACTIVITY	32	IS	1224.0000
ACTIVITY	34	IS	1591.0000
ACTIVITY	35	IS	1212.0000
ACTIVITY	37	IS	1591.0000
ACTIVITY	38	IS	1212.0000
ACTIVITY	40	IS	13590.0000
ACTIVITY	42	IS	16021.2801

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY LOWER BOUND	PRICE LOWER BOUND	ACTIVITY UPPER BOUND	PRICE UPPER BOUND
ACTIVITY	1	70	-552.4786	0	9999960.0000
ACTIVITY	2	46	-381.6299	70	472.4786
ACTIVITY	3	70	-12.2684	49	0.0000
ACTIVITY	4	70	-2.3681	51	0.0000
ACTIVITY	5	70	-110.8441	53	0.0000
ACTIVITY	6	46	-24.5821	50	0.0000
ACTIVITY	7	46	-1.4320	52	0.0000
ACTIVITY	8	46	-115.4794	54	0.0000
ACTIVITY	9	0	-9006575.0000	79	0.0000
ACTIVITY	10	0	-9010523.0000	80	0.0000
ACTIVITY	11	46	-938164.5957	71	-5535.0000
ACTIVITY	12	71	-1217.7037	0	9999540.0000
ACTIVITY	14	13	-5404.3164	71	461.9000
ACTIVITY	15	17	-903.7565	56	-356.0000
ACTIVITY	18	56	-536.0000	17	11.7565
ACTIVITY	21	70	-121094.9961	25	104.7379
ACTIVITY	24	25	-2454.7379	70	118744.9961
ACTIVITY	27	70	-175749.6867	32	710.6154
ACTIVITY	30	32	-1674.6154	70	174795.6867
ACTIVITY	33	70	-123372.[illegible]	33	[illegible].2712
ACTIVITY	36	32	-994.2712	70	122516.8679
ACTIVITY	39	65	-14760.0000	76	960.0000
ACTIVITY	41	42	-33663.7639	65	-10115.0000
ACTIVITY	43	70	.2433	0	9000000.4400
ACTIVITY	44	46	.9346	70	4.5233
ACTIVITY	45	71	-19.4365	69	0.0000

The Optimal Solution of the 25 Percent Navy Bean - 75 Percent Corn Production Model

START L. P. SOLVE

OPTIMAL SOLUTION (33)

OBJECTIVE FUNCTION= 60732.4046

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	50.0000
ACTIVITY	2	IS	150.0000
ACTIVITY	3	IS	2250.0000
ACTIVITY	4	IS	13500.0000
ACTIVITY	5	IS	265.0000
ACTIVITY	6	IS	2100.0000
ACTIVITY	7	IS	46500.0000
ACTIVITY	8	IS	510.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	1.0000
ACTIVITY	12	IS	1.0000
ACTIVITY	15	IS	.1272
ACTIVITY	18	IS	.8728
ACTIVITY	22	IS	.5690
ACTIVITY	25	IS	.4310
ACTIVITY	27	IS	.5614
ACTIVITY	30	IS	.4386
ACTIVITY	34	IS	.5313
ACTIVITY	37	IS	.4688
ACTIVITY	39	IS	.4681
ACTIVITY	41	IS	.5319
ACTIVITY	43	IS	130250.0000
ACTIVITY	44	IS	35700.0000
ACTIVITY	45	IS	831.7000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	341.6299	EXCESS	0.0000
ROW	2	PRICE	.4400	EXCESS	0.0000
ROW	3	PRICE	2.3700	EXCESS	0.0000
ROW	4	PRICE	.5800	EXCESS	0.0000
ROW	5	PRICE	.1800	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.3300	EXCESS	0.0000
ROW	8	PRICE	14.1500	EXCESS	0.0000
ROW	9	PRICE	15.0000	EXCESS	0.0000
ROW	10	PRICE	10.1385	EXCESS	0.0000
ROW	11	PRICE	.4500	EXCESS	0.0000
ROW	12	PRICE	0.0000	EXCESS	107.4632
ROW	13	PRICE	0.0000	EXCESS	148.0000
ROW	14	PRICE	0.0000	EXCESS	0.0000
ROW	15	PRICE	0.0000	EXCESS	135.2632
ROW	16	PRICE	0.0000	EXCESS	0.0000
ROW	17	PRICE	0.0000	EXCESS	93.4375
ROW	18	PRICE	0.0000	EXCESS	0.0000
ROW	19	PRICE	0.0000	EXCESS	82.0000
ROW	20	PRICE	16.4716	EXCESS	0.0000
ROW	21	PRICE	0.0000	EXCESS	555.0000
ROW	22	PRICE	0.0000	EXCESS	773.3000
ROW	23	PRICE	15.7640	EXCESS	0.0000
ROW	24	PRICE	6.0000	EXCESS	0.0000
ROW	25	PRICE	512.4786	EXCESS	0.0000
ROW	26	PRICE	-223.8575	EXCESS	0.0000
ROW	27	PRICE	986.6215	EXCESS	0.0000
ROW	28	PRICE	0.0000	EXCESS	1.0000
ROW	29	PRICE	-340.0000	EXCESS	0.0000
ROW	30	PRICE	-1933.2000	EXCESS	0.0000
ROW	31	PRICE	-1486.0000	EXCESS	0.0000
ROW	32	PRICE	-1591.0000	EXCESS	0.0000
ROW	33	PRICE	-11075.0000	EXCESS	0.0000
ROW	34	PRICE	-6575.0000	EXCESS	0.0000
ROW	35	PRICE	-10527.0000	EXCESS	0.0000

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	16	IS	590.7527
ACTIVITY	17	IS	541.2032
ACTIVITY	19	IS	810.6000
ACTIVITY	20	IS	807.0000
ACTIVITY	21	IS	2003.0000
ACTIVITY	23	IS	1996.2000
ACTIVITY	24	IS	2003.0000
ACTIVITY	26	IS	1996.2000
ACTIVITY	28	IS	1237.0000
ACTIVITY	29	IS	1224.0000
ACTIVITY	31	IS	1237.0000
ACTIVITY	32	IS	1224.0000
ACTIVITY	33	IS	2022.0000
ACTIVITY	35	IS	1212.0000
ACTIVITY	36	IS	2022.0000
ACTIVITY	38	IS	1212.0000
ACTIVITY	40	IS	13590.0000
ACTIVITY	42	IS	16021.2801

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY	PRICE	ACTIVITY	PRICE
		LOWER BOUND		UPPER BOUND	
ACTIVITY	1	70	-552.4786	0	8999960.0000
ACTIVITY	2	46	-381.6299	70	472.4736
ACTIVITY	3	70	-12.2684	49	0.0000
ACTIVITY	4	70	-2.3681	51	0.0000
ACTIVITY	5	70	-110.8441	53	0.0000
ACTIVITY	6	46	-24.5821	50	0.0000
ACTIVITY	7	45	-1.4320	52	0.0000
ACTIVITY	8	46	-115.4794	54	0.0000
ACTIVITY	9	0	-9006575.0000	79	0.0000
ACTIVITY	10	0	-9010523.0000	80	0.0000
ACTIVITY	11	46	-939164.5957	72	-4106.1269
ACTIVITY	12	72	-1446.6015	0	8999540.0000
ACTIVITY	13	0	-9000529.0000	71	-300.1022
ACTIVITY	14	71	-803.3624	55	2176.4000
ACTIVITY	15	17	-903.7565	56	-356.0000
ACTIVITY	18	56	-536.0000	17	11.7565
ACTIVITY	22	70	-179695.5583	75	550.2000
ACTIVITY	25	24	-4331.8205	70	176989.5583
ACTIVITY	27	70	-175749.6867	32	710.6154
ACTIVITY	30	32	-1674.6154	70	174785.6867
ACTIVITY	34	70	-164384.1571	38	430.6949
ACTIVITY	37	38	-1212.6949	70	163602.1571
ACTIVITY	39	65	-14760.0000	70	960.0000
ACTIVITY	41	42	-33663.7699	65	-10115.0000
ACTIVITY	43	70	.2433	0	9000000.4400
ACTIVITY	44	46	.9346	70	4.5233
ACTIVITY	45	72	-25.5869	69	0.0000

The Optimal Solution of the Navy Bean - Sugar Beet Production Model

START L. P. SOLVE

OPTIMAL SOLUTION (42)

OBJECTIVE FUNCTION= 193966.8000

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	.0000
ACTIVITY	2	IS	200.0000
ACTIVITY	3	IS	.0000
ACTIVITY	4	IS	.0000
ACTIVITY	5	IS	226.0000
ACTIVITY	7	IS	69000.0000
ACTIVITY	8	IS	349.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	1.0000
ACTIVITY	11	IS	1.0000
ACTIVITY	13	IS	1.0000
ACTIVITY	17	IS	.0000
ACTIVITY	19	IS	.0000
ACTIVITY	20	IS	1.0000
ACTIVITY	23	IS	.0000
ACTIVITY	26	IS	1.0000
ACTIVITY	29	IS	.0000
ACTIVITY	32	IS	1.0000
ACTIVITY	38	IS	1.0000
ACTIVITY	39	IS	.0000
ACTIVITY	42	IS	1.0000
ACTIVITY	44	IS	1.0000
ACTIVITY	46	IS	10000.0000
ACTIVITY	47	IS	872.2000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	1233.7000	EXCESS	0.0000
ROW	2	PRICE	.5804	EXCESS	0.0000
ROW	3	PRICE	30.0000	EXCESS	0.0000
ROW	4	PRICE	.8800	EXCESS	0.0000
ROW	5	PRICE	45.0000	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.4100	EXCESS	0.0000
ROW	8	PRICE	0.0000	EXCESS	.0000
ROW	9	PRICE	20.0000	EXCESS	0.0000
ROW	10	PRICE	0.0000	EXCESS	55.0000
ROW	11	PRICE	1.3936	EXCESS	0.0000
ROW	12	PRICE	0.0000	EXCESS	379.0000
ROW	13	PRICE	8.6043	EXCESS	0.0000
ROW	14	PRICE	0.0000	EXCESS	32.0000
ROW	15	PRICE	3.7091	EXCESS	0.0000
ROW	16	PRICE	0.0000	EXCESS	197.0000
ROW	17	PRICE	0.0000	EXCESS	.0000
ROW	18	PRICE	0.0000	EXCESS	36.0000
ROW	19	PRICE	57.9843	EXCESS	0.0000
ROW	20	PRICE	0.0000	EXCESS	.0000
ROW	21	PRICE	0.0000	EXCESS	16.0000
ROW	22	PRICE	0.0000	EXCESS	650.0000
ROW	23	PRICE	0.0000	EXCESS	[illegible]
ROW	24	PRICE	0.0000	EXCESS	[illegible]
ROW	25	PRICE	6.0000	EXCESS	0.0000
ROW	26	PRICE	-1159.0000	EXCESS	0.0000
ROW	27	PRICE	-3241.0000	EXCESS	0.0000
ROW	28	PRICE	-5173.0000	EXCESS	0.0000
ROW	29	PRICE	-610.5000	EXCESS	0.0000
ROW	30	PRICE	0.0000	EXCESS	1.0000
ROW	31	PRICE	3.6000	EXCESS	0.0000
ROW	32	PRICE	-1596.2000	EXCESS	0.0000
ROW	33	PRICE	-1237.0000	EXCESS	0.0000
ROW	34	PRICE	0.0000	EXCESS	1.0000
ROW	35	PRICE	0.0000	EXCESS	0.0000
ROW	36	PRICE	13.0000	EXCESS	0.0000
ROW	37	PRICE	-1212.0000	EXCESS	[illegible]
ROW	38	PRICE	-6575.0000	EXCESS	[illegible]
ROW	39	PRICE	-10523.0000	EXCESS	[illegible]
ROW	40	PRICE	-21[illegible]3.0000	EXCESS	[illegible]

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	5	IS	14.1500
ACTIVITY	12	IS	1275.0000
ACTIVITY	14	IS	1161.0000
ACTIVITY	15	IS	294.2435
ACTIVITY	16	IS	141.5845
ACTIVITY	18	IS	842.0000
ACTIVITY	21	IS	996.2557
ACTIVITY	22	IS	416.0500
ACTIVITY	24	IS	[illegible]
ACTIVITY	25	IS	[illegible]
ACTIVITY	27	IS	254.0000
ACTIVITY	28	IS	317.1455
ACTIVITY	30	IS	229.0000
ACTIVITY	33	IS	2022.0000
ACTIVITY	34	IS	1591.0000
ACTIVITY	35	IS	1212.0000
ACTIVITY	36	IS	2222.0000
ACTIVITY	37	IS	1551.0000
ACTIVITY	40	IS	137.6440
ACTIVITY	41	IS	3032.0000
ACTIVITY	43	IS	4624.0000
ACTIVITY	45	IS	.1404

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY LOWER BOUND	PRICE	ACTIVITY UPPER BOUND	PRICE
ACTIVITY	1	0	-9000040.0000	45	320.3186
ACTIVITY	2	45	-400.3186	0	8999960.0000
ACTIVITY	3	0	-9000000.8800	51	0.0000
ACTIVITY	4	0	-9000000.4700	53	0.0000
ACTIVIT	5	0	-9000014.1500	55	0.0000
ACTIVITY	6	45	-363.8660	52	0.0000
ACTIVITY	7	45	-1.4544	54	0.0000
ACTIVITY	8	45	-231.9521	56	0.0000
ACTIVITY	9	45	-381113.3492	31	-3070.9661
ACTIVITY	10	31	-16707.4384	12	-8188.9088
ACTIVITY	11	12	-25374.2750	70	-.0000
ACTIVITY	14	13	-862.5365	57	2706.3000
ACTIVITY	20	19	-906.1331	58	917.0265
ACTIVITY	23	22	-2699.0820	60	1135.1301
ACTIVITY	26	25	-2639.0820	61	1135.1301
ACTIVITY	29	28	-1244.7622	62	1354.8860
ACTIVITY	32	31	-1239.1239	63	1354.8860
ACTIVITY	35	34	-2607.5602	64	1697.6250
ACTIVITY	38	37	-2588.7250	65	1697.6250
ACTIVITY	39	40	-10226.3190	66	960.0000
ACTIVITY	42	41	-3862.6917	67	2678.4750
ACTIVITY	44	43	-8492.9622	72	5764.4190
ACTIVITY	46	45	22.7936	0	9000030.0000
ACTIVITY	47	40	-6.0747	12	-.9105

The Optimal Solution of the 25 Percent Navy Bean - 75 Percent Sugar Beet Production Model

START L. P. SOLVE

OPTIMAL SOLUTION (30)

OBJECTIVE FUNCTION= 174960.0500

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	50.0000
ACTIVITY	2	IS	150.0000
ACTIVITY	3	IS	2250.0000
ACTIVITY	4	IS	13300.0000
ACTIVITY	5	IS	285.0000
ACTIVITY	6	IS	169.5000
ACTIVITY	7	IS	51750.0000
ACTIVITY	8	IS	285.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	.0000
ACTIVITY	11	IS	1.0000
ACTIVITY	13	IS	1.0000
ACTIVITY	15	IS	.6183
ACTIVITY	16	IS	.3817
ACTIVITY	22	IS	.5690
ACTIVITY	25	IS	.4310
ACTIVITY	27	IS	.6250
ACTIVITY	30	IS	.3750
ACTIVITY	34	IS	.5313
ACTIVITY	37	IS	.4688
ACTIVITY	39	IS	1.0000
ACTIVITY	41	IS	1.0000
ACTIVITY	43	IS	1.0000
ACTIVITY	45	IS	130250.0000
ACTIVITY	46	IS	7500.0000
ACTIVITY	47	IS	1371.7000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	1233.7000	EXCESS	0.0000
ROW	2	PRICE	.4400	EXCESS	0.0000
ROW	3	PRICE	30.0000	EXCESS	0.0000
ROW	4	PRICE	.8800	EXCESS	0.0000
ROW	5	PRICE	45.0000	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.4100	EXCESS	0.0000
ROW	8	PRICE	14.1500	EXCESS	0.0000
ROW	9	PRICE	20.0000	EXCESS	0.0000
ROW	10	PRICE	0.0000	EXCESS	55.0000
ROW	11	PRICE	0.0000	EXCESS	1[illegible].0000
ROW	12	PRICE	0.0000	EXCESS	0.0000
ROW	13	PRICE	0.0000	EXCESS	14[illegible].0000
ROW	14	PRICE	0.0000	EXCESS	0.0000
ROW	15	PRICE	0.0000	EXCESS	156.2500
ROW	16	PRICE	0.0000	EXCESS	0.0000
ROW	17	PRICE	0.0000	EXCESS	93.4375
ROW	18	PRICE	0.0000	EXCESS	0.0000
ROW	19	PRICE	0.0000	EXCESS	141.0000
ROW	20	PRICE	0.0000	EXCESS	172.0000
ROW	21	PRICE	0.0000	EXCESS	17[illegible].0000
ROW	22	PRICE	0.0000	EXCESS	[illegible]
ROW	23	PRICE	10.5230	EXCESS	0.0000
ROW	24	PRICE	0.0000	EXCESS	513.3[illegible]
ROW	25	PRICE	0.0000	EXCESS	0.0000
ROW	26	PRICE	-369.9950	EXCESS	0.0000
ROW	27	PRICE	-2690.6950	EXCESS	0.0000
ROW	28	PRICE	0.0000	EXCESS	0.0000
ROW	29	PRICE	1531.5000	EXCESS	0.0000
ROW	30	PRICE	-[illegible]42.0000	EXCESS	0.0000
ROW	31	PRICE	-1[illegible].2000	EXCESS	0.0000
ROW	32	PRICE	-1466.0000	EXCESS	0.0000
ROW	33	PRICE	-1[illegible]1.0000	EXCESS	0.0000
ROW	34	PRICE	-11[illegible].0000	EXCESS	0.0000
ROW	35	PRICE	-3[illegible]32.0000	EXCESS	0.0000
ROW	36	PRICE	-4624.0000	EXCESS	0.0000
ROW	37	PRICE	-6575.0000	EXCESS	0.0000
ROW	38	PRICE	-21[illegible].0000	EXCESS	0.0000

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	14	IS	1161.0000
ACTIVITY	16	IS	1511.4318
ACTIVITY	17	IS	1391.0265
ACTIVITY	19	IS	1511.4318
ACTIVITY	20	IS	1391.0265
ACTIVITY	21	IS	2000.0000
ACTIVITY	23	IS	2719.1301
ACTIVITY	24	IS	2003.0000
ACTIVITY	26	IS	2719.1301
ACTIVITY	28	IS	1237.0000
ACTIVITY	29	IS	2036.8860
ACTIVITY	31	IS	1237.0000
ACTIVITY	32	IS	2036.8860
ACTIVITY	33	IS	2022.0000
ACTIVITY	35	IS	1212.0000
ACTIVITY	36	IS	2022.0000
ACTIVITY	38	IS	1212.0000
ACTIVITY	40	IS	13590.0000
ACTIVITY	42	IS	3041.0000
ACTIVITY	44	IS	5173.0000

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY	PRICE	ACTIVITY	PRICE
		LOWER BOUND		UPPER BOUND	
ACTIVITY	1	0	-9000040.0000	73	328.9950
ACTIVITY	2	73	-408.9950	0	8999959.0000
ACTIVITY	3	0	-9000030.3800	31	0.0000
ACTIVITY	4	0	-9000000.4700	53	0.0000
ACTIVITY	5	0	-9000014.1500	55	0.0000
ACTIVITY	6	73	-371.5442	52	0.0000
ACTIVITY	7	73	-1.4796	54	0.0000
ACTIVITY	8	73	-237.0559	56	0.0000
ACTIVITY	9	0	-9006575.0000	84	0.0000
ACTIVITY	10	0	-9010523.0000	70	-.0000
ACTIVITY	11	0	-9021063.0000	85	0.0000
ACTIVITY	12	0	-9000460.0000	75	1071.6050
ACTIVITY	13	76	-2060.6050	0	8999471.0000
ACTIVITY	15	0	-9000356.0000	77	426.0000
ACTIVITY	18	20	-1300.1682	0	8999344.0000
ACTIVITY	22	0	-9001353.0000	75	550.2000
ACTIVITY	25	24	-4331.8205	0	8998647.0000
ACTIVITY	27	0	-9000482.0000	79	294.0000
ACTIVITY	30	31	-2136.8495	0	8999515.0000
ACTIVITY	34	0	-9000391.0000	83	1200.0000
ACTIVITY	37	38	-2034.3898	0	8999509.0000
ACTIVITY	39	0	-9010115.0000	81	560.0000
ACTIVITY	41	0	-9001322.0000	82	1710.0000
ACTIVITY	43	0	-9002914.0000	83	1720.0000
ACTIVITY	45	49	0.0000	73	.5815
ACTIVITY	46	73	22.6201	0	9000030.0000
ACTIVITY	47	0	-9000006.0000	72	0.0000

The Optimal Solution of the 50 Percent Navy Bean - 50 Percent Sugar Beet Production Model

START L. P. SOLVE

OPTIMAL SOLUTION (33)

OBJECTIVE FUNCTION= 155979.5000

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	100.0000
ACTIVITY	2	IS	100.0000
ACTIVITY	3	IS	4500.0000
ACTIVITY	4	IS	27000.0000
ACTIVITY	5	IS	530.0000
ACTIVITY	6	IS	113.0000
ACTIVITY	7	IS	34500.0000
ACTIVITY	8	IS	170.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	.0000
ACTIVITY	11	IS	1.0000
ACTIVITY	13	IS	1.0000
ACTIVITY	15	IS	.7455
ACTIVITY	19	IS	.2545
ACTIVITY	21	IS	.5726
ACTIVITY	24	IS	.4274
ACTIVITY	27	IS	.7500
ACTIVITY	30	IS	.2500
ACTIVITY	33	IS	.5833
ACTIVITY	36	IS	.4167
ACTIVITY	39	IS	1.0000
ACTIVITY	41	IS	1.0000
ACTIVITY	43	IS	1.0000
ACTIVITY	45	IS	260500.0000
ACTIVITY	46	IS	5000.0000
ACTIVITY	47	IS	1492.0000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	1233.7000	EXCESS	0.0000
ROW	2	PRICE	.4400	EXCESS	0.0000
ROW	3	PRICE	30.0000	EXCESS	0.0000
ROW	4	PRICE	.6500	EXCESS	0.0000
ROW	5	PRICE	45.0000	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.4100	EXCESS	0.0000
ROW	8	PRICE	14.1500	EXCESS	0.0000
ROW	9	PRICE	20.0000	EXCESS	0.0000
ROW	10	PRICE	0.0000	EXCESS	55.0000
ROW	11	PRICE	0.0000	EXCESS	193.0000
ROW	12	PRICE	0.0000	EXCESS	0.0000
ROW	13	PRICE	0.0000	EXCESS	34.0000
ROW	14	PRICE	0.0000	EXCESS	0.0000
ROW	15	PRICE	0.0000	EXCESS	147.5000
ROW	16	PRICE	0.0000	EXCESS	0.0000
ROW	17	PRICE	0.0000	EXCESS	15.5667
ROW	18	PRICE	0.0000	EXCESS	0.0000
ROW	19	PRICE	0.0000	EXCESS	91.0000
ROW	20	PRICE	0.0000	EXCESS	222.0000
ROW	21	PRICE	0.0000	EXCESS	222.0000
ROW	22	PRICE	0.0000	EXCESS	5[illegible]
ROW	23	PRICE	1[illegible].5230	EXCESS	[illegible]
ROW	24	PRICE	[illegible]	EXCESS	61[illegible]
ROW	25	PRICE	8.0000	EXCESS	[illegible]
ROW	26	PRICE	-3[illegible].[illegible]50	EXCESS	[illegible]
ROW	27	PRICE	-26[illegible].6[illegible]	EXCESS	[illegible]
ROW	28	PRICE	0.0000	EXCESS	[illegible]
ROW	29	PRICE	1531.[illegible]	EXCESS	[illegible]
ROW	30	PRICE	-942.0000	EXCESS	[illegible]
ROW	31	PRICE	-2[illegible]	EXCESS	[illegible]
ROW	32	PRICE	-146[illegible]	EXCESS	[illegible]
ROW	33	PRICE	-2[illegible]	EXCESS	[illegible]
ROW	34	PRICE	-11[illegible]	EXCESS	[illegible]
ROW	35	PRICE	-3[illegible]	EXCESS	[illegible]
ROW	36	PRICE	-4624.0000	EXCESS	[illegible]
ROW	37	PRICE	-6[illegible]75.[illegible]	EXCESS	[illegible]
ROW	38	PRICE	-21[illegible]	EXCESS	[illegible]

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	14	IS	1151.0000
ACTIVITY	16	IS	1511.4315
ACTIVITY	17	IS	1391.0265
ACTIVITY	19	IS	1511.4315
ACTIVITY	20	IS	1351.0265
ACTIVITY	22	IS	2866.1591
ACTIVITY	23	IS	2719.1301
ACTIVITY	25	IS	2866.1591
ACTIVITY	26	IS	2719.1301
ACTIVITY	28	IS	1237.0000
ACTIVITY	29	IS	2086.9550
ACTIVITY	31	IS	1237.0000
ACTIVITY	32	IS	2086.9550
ACTIVITY	34	IS	1591.0000
ACTIVITY	35	IS	1212.0000
ACTIVITY	37	IS	1591.0000
ACTIVITY	38	IS	1212.0000
ACTIVITY	40	IS	13590.0000
ACTIVITY	42	IS	3041.0000
ACTIVITY	44	IS	5173.0000

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY LOWER BOUND	PRICE	ACTIVITY UPPER BOUND	PRICE
ACTIVITY	1	0	-9000040.0000	73	328.9950
ACTIVITY	2	73	-438.9950	0	8999950.0000
ACTIVITY	3	0	-9000000.6600	51	0.0000
ACTIVITY	4	0	-9000000.4700	53	0.0000
ACTIVITY	5	0	-9000014.1500	55	0.0000
ACTIVITY	6	73	-371.5442	52	0.0000
ACTIVITY	7	73	-1.4796	54	0.0000
ACTIVITY	8	73	-237.0559	56	0.0000
ACTIVITY	9	0	-9006575.0000	94	.0000
ACTIVITY	10	0	-9010523.0000	71	-.0000
ACTIVITY	11	0	-9021063.0000	85	0.0000
ACTIVITY	12	0	-9000460.0000	76	1171.6050
ACTIVITY	13	76	-2060.6250	0	8999471.0000
ACTIVITY	15	0	-9000356.0000	77	486.0000
ACTIVITY	18	20	-1300.1682	0	8999644.0000
ACTIVITY	21	0	-9001175.0000	25	753.5597
ACTIVITY	24	25	-3103.5697	0	8998825.0000
ACTIVITY	27	0	-9000482.0000	79	994.0000
ACTIVITY	30	31	-2136.8495	0	8999518.0000
ACTIVITY	33	0	-9000378.0000	37	915.2500
ACTIVITY	36	37	-1571.2500	0	8999622.0000
ACTIVITY	39	0	-9010115.0000	81	960.0000
ACTIVITY	41	0	-9001322.0000	82	1710.0000
ACTIVITY	43	0	-9002914.0000	83	1710.0000
ACTIVITY	45	49	0.0000	73	.5916
ACTIVITY	46	73	22.6271	0	9000031.0000
ACTIVITY	47	0	-9000006.0000	72	0.0000

The Optimal Solution of the 75 Percent Navy Bean - 25 Percent Sugar Beet Production Model

START L. P. SOLVE

OPTIMAL SOLUTION (32)

OBJECTIVE FUNCTION= 13[illegible]435.55[illegible]

ACTIVITIES IN SOLUTION

ACTIVITY	1	IS	150.0000
ACTIVITY	2	IS	50.0000
ACTIVITY	3	IS	6750.0000
ACTIVITY	4	IS	40500.0000
ACTIVITY	5	IS	795.0000
ACTIVITY	6	IS	56.5000
ACTIVITY	7	IS	17250.0000
ACTIVITY	8	IS	45.0000
ACTIVITY	9	IS	1.0000
ACTIVITY	10	IS	.0000
ACTIVITY	11	IS	1.0000
ACTIVITY	13	IS	1.0000
ACTIVITY	15	IS	.0725
ACTIVITY	19	IS	.1272
ACTIVITY	22	IS	.[illegible]
ACTIVITY	25	IS	.143[illegible]
ACTIVITY	27	IS	.8750
ACTIVITY	30	IS	.1250
ACTIVITY	35	IS	.7891
ACTIVITY	38	IS	.2118
ACTIVITY	39	IS	1.0000
ACTIVITY	41	IS	1.0000
ACTIVITY	43	IS	1.0000
ACTIVITY	45	IS	390750.0000
ACTIVITY	46	IS	2500.0000
ACTIVITY	47	IS	1306.7000

SHADOW PRICES AND SLACKS

ROW	1	PRICE	1233.7000	EXCESS	0.0000
ROW	2	PRICE	.4400	EXCESS	0.0000
ROW	3	PRICE	30.0000	EXCESS	0.0000
ROW	4	PRICE	.5000	EXCESS	0.0000
ROW	5	PRICE	45.0000	EXCESS	0.0000
ROW	6	PRICE	.4700	EXCESS	0.0000
ROW	7	PRICE	.4100	EXCESS	0.0000
ROW	8	PRICE	14.1500	EXCESS	0.0000
ROW	9	PRICE	20.0000	EXCESS	0.0000
ROW	10	PRICE	0.0000	EXCESS	55.0000
ROW	11	PRICE	0.0000	EXCESS	19[illegible].0000
ROW	12	PRICE	0.0000	EXCESS	0.0000
ROW	13	PRICE	0.0000	EXCESS	14[illegible].0000
ROW	14	PRICE	0.0000	EXCESS	0.0000
ROW	15	PRICE	0.0000	EXCESS	13[illegible].75[illegible]
ROW	16	PRICE	0.0000	EXCESS	0.0000
ROW	17	PRICE	0.0000	EXCESS	7.6271
ROW	18	PRICE	0.0000	EXCESS	0.0000
ROW	19	PRICE	0.0000	EXCESS	41.0000
ROW	20	PRICE	0.0000	EXCESS	[illegible]72.0000
ROW	21	PRICE	0.0000	EXCESS	[illegible]72.0000
ROW	22	PRICE	0.0000	EXCESS	33[illegible].0000
ROW	23	PRICE	10.5230	EXCESS	0.0000
ROW	24	PRICE	[illegible]	EXCESS	51[illegible]
ROW	25	PRICE	[illegible]	EXCESS	0.0000
ROW	26	PRICE	-36[illegible].9[illegible]	EXCESS	0.0000
ROW	27	PRICE	-259[illegible].6[illegible]	EXCESS	0.0000
ROW	28	PRICE	0.0000	EXCESS	0.0000
ROW	29	PRICE	1531.60[illegible]	EXCESS	0.0000
ROW	30	PRICE	-942.0000	EXCESS	0.0000
ROW	31	PRICE	-1[illegible]03.[illegible]	EXCESS	0.0000
ROW	32	PRICE	-145[illegible].[illegible]	EXCESS	0.0000
ROW	33	PRICE	-121[illegible].[illegible]	EXCESS	0.0000
ROW	34	PRICE	-11[illegible]75.0[illegible]	EXCESS	0.0000
ROW	35	PRICE	-3[illegible].[illegible]	EXCESS	0.0000
ROW	36	PRICE	-46[illegible]4.[illegible]	EXCESS	0.0000
ROW	37	PRICE	-6575.[illegible]	EXCESS	0.0000
ROW	38	PRICE	-21[illegible].[illegible]	EXCESS	0.0000

COST OF FORCING IN NONOPTIMAL ACTIVITIES

ACTIVITY	14	IS	11[illegible]1.0000
ACTIVITY	15	IS	1511.431[illegible]
ACTIVITY	17	IS	1391.0865
ACTIVITY	18	IS	1511.431[illegible]
ACTIVITY	20	IS	1391.0865
ACTIVITY	21	IS	2[illegible]
ACTIVITY	23	IS	2719.1301
ACTIVITY	24	IS	2003.0000
ACTIVITY	26	IS	2719.1301
ACTIVITY	28	IS	1237.0000
ACTIVITY	29	IS	2256.9860
ACTIVITY	31	IS	1237.0000
ACTIVITY	32	IS	2256.9860
ACTIVITY	33	IS	2022.0000
ACTIVITY	34	IS	1591.0000
ACTIVITY	36	IS	2022.0000
ACTIVITY	37	IS	1591.0000
ACTIVITY	40	IS	1359[illegible].0000
ACTIVITY	42	IS	3041.0000
ACTIVITY	44	IS	5173.0000

PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS

		ACTIVITY LOWER BOUND	PRICE	ACTIVITY UPPER BOUND	PRICE
ACTIVITY	1	0	-9000240.0000	73	328.9950
ACTIVITY	2	73	-428.9950	0	[illegible]99996[illegible].0000
ACTIVITY	3	0	-9000000.3600	51	0.0000
ACTIVITY	4	0	-9000000.4700	53	0.0000
ACTIVITY	5	0	-9000014.1500	55	0.0000
ACTIVITY	6	73	-371.5442	52	0.0000
ACTIVITY	7	73	-1.4796	54	0.0000
ACTIVITY	8	73	-237.0550	56	0.0000
ACTIVITY	9	0	-9006575.0000	84	0.0000
ACTIVITY	10	0	-9010523.0000	70	-.0000
ACTIVITY	11	0	-9021063.0000	85	0.0000
ACTIVITY	12	0	-9000460.0000	76	1[illegible]71.6050
ACTIVITY	13	76	-2060.6050	0	[illegible]999471.0000
ACTIVITY	15	0	-9000356.0000	77	496.0000
ACTIVITY	16	2[illegible]	-13[illegible]0.1682	[illegible]	9999644.0000
ACTIVITY	22	0	-9001353.0000	78	550.2000
ACTIVITY	25	24	-4331.8205	[illegible]	[illegible]998647.0000
ACTIVITY	27	0	-9000492.0000	79	[illegible]84.0000
ACTIVITY	30	31	-2136.8495	0	[illegible]999518.0000
ACTIVITY	35	0	-9000402.0000	37	771.3425
ACTIVITY	38	37	-1575.3625	[illegible]	[illegible]999598.0000
ACTIVITY	39	0	-9010115.0000	81	[illegible]60.0000
ACTIVITY	41	0	-9001322.0000	82	1713.0000
ACTIVITY	43	0	-9002914.0000	83	1710.0000
ACTIVITY	45	49	0.0000	7[illegible]	.5[illegible]
ACTIVITY	46	73	22.6201	0	9000030.0000
ACTIVITY	47	0	-9000006.0000	72	0.0000

APPENDIX C

Linear Programming Package by Harsh and Black (1975)

Linear Program Package

A linear programming package designed by Harsh and Black (1975) was used to solve the MILP models. In order to use this package one needs to provide the following requirements:

1. Matrix size (number of rows and columns)
2. Coefficient information
3. Row information
4. Objective values

This package was adopted because it can handle modest size of linear programming where the objective is to maximize subject to series of constraints.

In the MILP models, some constraints were added to force number of activities to be integer rather than functional number so that the LP package can handle it.

Staff Paper No. 75-10

AGRICULTURAL ECONOMICS LINEAR PROGRAM PACKAGE
VERSION 2 -- APRIL 1975

By

Stephen B. Harsh And J. Roy Black
Michigan State University

INTRODUCTION

A linear programming package designed to handle modest-sized linear programming problems. The package will execute on a CDC-6500 computer. It is a particularly useful package for teaching and some research problems because it is relatively simple to utilize from a user's viewpoint.

The objective of the package is to handle linear programming problems of the following nature.

Maximize:

$$(1) \quad z = \sum_{j=1}^{n} c_j x_j$$

Subject To:

$$(2) \quad \sum_{j=1}^{n} a_{ij} \; x_j \; \leq, =, \text{ or } \geq$$

$$x_j \geq 0$$

Where:

$$i = 1,2,\ldots,m \text{ and}$$
$$j = 1,2,\ldots,n$$

To minimize Z, multiply c_j's by -1.

The package requires that c_j's, a_{ij}'s, and b_i's be inputted. Slack and artificial variables are automatically added.

PACKAGE DESCRIPTION

Input Deck:

To use the linear programming package, the user will have to supply the standard computer control cards (e.g., PNC, job card, password card, etc.) which will be followed by the data deck for the package. The deck is as follows:

CARD 1: Name and Job Description.

|- - - - - - - - - - - - A - - - - - - - - - - - - - . . . .

A = Alpha-numeric description of the linear programming problem (60 characters maximum)

CARD 2: Options Used.

| A | B | C | D | E | F |

When A is equal to:
0 = No print; 1 = Print activities in solution.

When B is equal to:
0 = No print; 1 = Print shadow prices and slack values.

When C is equal to:
0 = No print; 1 = Print cost of forcing in nonoptimal activitie

When D is equal to:
0 = No print; 1 = Print initial LP matrix for verification purposes.

When E is equal to:
0 = No print; 1 = Print price ranges.

When F (save and restore matrix option) is equal to:
0 = Neither save nor restore matrix; 1 = Save matrix from this analysis for adjustments in next analysis; 2 = Restore matrix from previous analysis for adjustments in this analysis; 3 = Both save matrix from this analysis for adjustments in next analysis and restore matrix from previous analysis for adjustments in this analysis.

CARD 3: Matrix Size Card.

|- M -|- N -|

M = Number of rows
N = Number of columns

CARD 4 To **CARD F-1**: Coefficient Information.

```
|- I -|- J -|----A  ----------|
                   ij
```

I = Row number (integer value)
J = Column number (integer value)
A_{ij} = Coefficient for row I and column J. (Decimal value. Decimal must be punched.)

NOTE: Only need to enter nonzero A_{ij} information.

CARD F: End of Coefficient Information.

(Blank Card)

```
|--------------- . . . . .
```

CARD F+1 To **G-1**: Row Information.

```
|- I -| R |------B  --------|
                  i
```

I = Row number (integer value)
R = Restriction type (integer value)

Code	Restriction Type
1	(LE) $\leq$
2	(EQ) $=$
3	(GE) $\geq$

B_i = Right-hand side value for row I. (Decimal value. Decimal must be punched.)

NOTE: A card is used for each row.

CARD G: End of Row Information.

(Blank Card)

```
|---------------- . . . . .
```

CARD G+1 To **H-1**: Objective Values.

```
|- J -|-------C  --------|
               j
```

J = Column number (integer value)
C_j = Objective value for column J. (Decimal value. Decimal must be punched.)

NOTE: Only need to enter nonzero C_j information.

<u>CARD H</u>: End of Objective Values Information.
(Blank Card)

|- - - - - - - - - - - - - - - - - . . . . .

<u>CARD H+1</u>: Next Analysis Name and Job Description.

|- - - - - - - - - - - - - - - - - . . . .
A

A = Alpha-numeric description of linear programming problem. If STOP is coded in columns 1-4 of card, this will terminate operation of package. If not, code rest of deck for next analysis as for previous analysis starting with Card 2.

ERROR INFORMATION

The package checks for several input errors. When one is found, it generally indicates the card at which the error occurs and nature of the error. The analysis is terminated when one is found.

Errors particularly common are indicating row or column values greater than matrix size or a wrong restriction type.

OUTPUT OF ANALYSIS

The output of the package includes the following:

(1) List of data inputted.

a) a_{ij}

b) b_i and restriction type

c) c_j

(2) Type of solution.

a) Solution exists

b) System is inconsistent

c) System is unbounded

(3) If a optimal solution exists, the following information is printed:

a) Value of objective function

b) Activities in the optimal solution

c) Values of the restrictions

d) Cost of forcing the nonbasis activities into the optimal solution

e) Price range over which the optimal solution held

```
      PROGRAM LPCOMP (INPUT,OUTPUT)
C      LINEAR PROGRAM WRITTEN BY STEVE HARSH AND ROY BLACK,DEPT.
C      OF AGR. ECON. MICHIGAN STATE UNIVERSITY,EAST LANSING,MI.
C      VIA THE BIG M METHOD.SUBROUTINE ROWSET SETS UP THE SLACK,
C      SURPLUS AND ARTIFICIAL VARIABLES INCLUDING ATTACHING THE
C      APPROPRIATE PRICES.SUBROUTINE LPSOL IS THE SIMPLES ALGORITHM
C      ORIGINAL SIMPLEX METHOD USED.ARTIFICIAL VARIABLES HANDLED
      COMMON/  /DPM(60,180),RHS(60),INACT(60),ISACOL(60),IRWTY(60),
     1 OBJ(180),ZC(180)
      DIMENSION ACT(180),PERSON(6)
      DIMENSION JRPL(180),JRPU(180),OBJL(180),OBJU(180)
    1 FORMAT(/)
  300 READ 65,(PERSON(I),I=1,6,1),J
   65 FORMAT(6A4,5X,I1)
      IF(J.GT.0)GO TO 145
      PRINT 66,(PERSON(I),I=1,6,1)
   66 FORMAT(1H1,1X,///,' LINEAR PROGRAMMING ANALYSIS FOR ',6A4,/////)
      DO 80 I=1,60
      RHS(I)=0.
      IRWTY(I)=0
      INACT(I)=0
      ISACOL(I)=0
      DO 82 J=1,180
   82 DPM(I,J)=0.
   80 CONTINUE
      DO 84 J=1,180
      JRPU(J)=0
      OBJL(J)=0.
      JRPL(J)=0
      OBJU(J)=9000000.
      ACT(J)=0.
      OBJ(J)=0.
   84 ZC(J)=0.
      READ 4,IOPT1,IOPT2,IOPT3,IOPT4,IOPT5
    4 FORMAT(6I1)
      READ 5,NOROW,NOCOL
    5 FORMAT(2I3)
      SUM=0
      ICARD=0
  100 READ 6,I,J,X
    6 FORMAT(2I3,F17.4)
      ICARD=ICARD+1
      IF(X.EQ.0.0.AND.I.EQ.0.AND.J.EQ.0)GO TO 110
      IF(I.LT.1.OR.I.GT.NOROW) CALL  ERR(1,ICARD,SUM)
      IF(J.LT.1.OR.J.GT.NOCOL) CALL  ERR(1,ICARD,SUM)
```

```
      DPM(I,J)=X
      GO TO 100
  110 JCOL=NOCOL
  112 READ 7,I,IRHSTY,RHSV
    7 FORMAT(I3,I1,F15.5)
      ICARD=ICARD+1
      II=I+IRHSTY+RHSV
      IF(II.EQ.0)GO TO 120
      IF(I.LT.1.OR.I.GT.NOROW) CALL ERR(2,ICARD,VUM)
      CALL ROWSET(I,JCOL,IRHSTY,RHSV,ICARD,SUM)
      GO TO 112
  120 READ 9,J,X
    9 FORMAT(I3,F16.3)
      IF(X .EQ.0.0.AND.J.EQ.0)GO TO 130
  121 ICARD=ICAPD+1
      IF(J.LT.1.OR.J.GT.NOCOL) CALL ERR(3,ICARD,SUM)
      OBJ(J)=X
      GO TO 120
  130 IF(SUM.EQ.0.0)GO TO 125
      PRINT 48
   48 FORMAT(31H PROGRAM TERMINATED,FAULTY DATA)
      GO TO 195
  125 IF(IOPT4.EQ.0)GO TO 141
      PRINT 1
      CALL LPDUMP(NOROW,NOCOL)
  141 CALL LPSCL(NOPOW,JCOL,IOPT5,ISOLTY,NOITER,OBJV)
      IF(ISOLTY.GT.0)GO TO 195
  151 DO 160 I=1,NOPOW
      DO 165 J=1,JCOL
      IF(INACT(I).NE.J)GO TO 165
      ACT(J)=RHS(I)
      GO TO 160
  165 CONTINUE
  160 CONTINUE
      IF(IOPT1.EQ.0)GO TO 175
      PRINT 49
   49 FORMAT(17H OPTIMAL SOLUTION)
      PRINT 1
   60 FORMAT(20H OBJECTIVE FUNCTION=,2X,F15.4)
      PRINT 60,OBJV
      PRINT 1
      DO 170 J=1,NOCOL
      IF(ACT(J).EQ.0)GO TO 170
   50 FORMAT(9H ACTIVITY,2X,I3,2X,3H IS,F15.4)
      PRINT 50,J,ACT(J)
```

```
170 CONTINUE
175 IF(IOPT2.EQ.0) GO TO 185
    PRINT 1
    PRINT 1
    PRINT 52
 52 FORMAT(35H SHADOW PRICES,SURPLUSES,AND SLACKS)
    DO 180 I=1,NOROW
    J=ISACCL(I)
    IF(IRWTY(I) .EQ. 3)J=J+1
    PRINT 54,I,ZC(ISACOL(I)),ACT(J)
 54 FORMAT(4H ROW,2X,I4,2X,6H PRICE,2X,F15.4,2X,7H EXCESS,2X,F15.4)
180 CONTINUE
185 IF(ICPT3.EQ.0)GO TO 197
    PRINT 1
    PRINT 1
    PRINT 56
 56 FORMAT(41H COST OF FORCING IN NONOPTIMAL ACTIVITIES)
    DO 190 J=1,NOCOL
    IF(ZC(J).EQ.0.0)GO TO 190
    PRINT 58,J,ZC(J)
 58 FORMAT(9H ACTIVITY,2X,I3,3H IS,F15.4)
190 CONTINUE
    PRINT 1
    PRINT 1
197 IF(IOPT5.EQ.0)GO TO 195
    DO 70 I=1,NOROW
    Z1=-9000000.
    K1=0
    Z2= 9000000.
    K2=0
    DO 72 J=1,JCOL
    IF(DPM(I,J) .EQ. 0.0)GO TO 72
    X=ZC(J)/DPM(I,J)
    IF(X)74,72,76
 74 IF(X.LE.Z1)GO TO 72
    K1=J
    Z1=X
    GO TO 72
 76 IF(X.GE.Z2)GO TO 72
    K2=J
    Z2=X
 72 CONTINUE
    JRPL(INACT(I))=K2
    OBJL(INACT(I))=OBJ(INACT(I))-Z2
    JRPU(INACT(I))=K1
```

```
      OBJU(INACT(I))=OBJ(INACT(I))-Z1
   70 CONTINUE
      PRINT 59
   59 FORMAT(46H PRICE RANGE OVER WHICH OPTIMAL SOLUTION HOLDS)
      PRINT 1
  500 FORMAT(26X,12H LOWER BOUND,10X,12H UPPER BOUND)
      PRINT 600
  605 FORMAT(19X,9H ACTIVITY,5X,6H PRICE,5X,9H ACTIVITY,5X,6H PRICE)
      PRINT 605
   85 FORMAT(9H ACTIVITY,2X,I4,2X,I4,2X,F15.4,2X,I4,F15.4)
      DO 86 J=1,NOCOL
      IF(ZC(J)) 86,87,86
   87 PRINT 85,J,JRPL(J),OBJL(J),JRPU(J),OBJU(J)
   86 CONTINUE
  105 CONTINUE
      GO TO 300
  145 STOP
      END
```

```
      SUBROUTINE  ERR(ITYPE,ICARD,SUM)
      SUM=SUM+1
      GO TO(1,2,3,4),ITYPE
    1 PRINT 10,ICARD
      RETURN
    2 PRINT 12,ICARD
      RETURN
    3 PRINT 14,ICARD
      RETURN
    4 PRINT 15, ICARD
      RETURN
   10 FORMAT(40H INPUT ERROR,COEFFICIENT MATRIX, AT CARD,2X,I5)
   12 FORMAT(31H INPUT ERROR,RHS VECTOR,AT CARD,2X,I5)
   14 FORMAT(33H INPUT ERROR,OBJ FUNCTION,AT CARD,2X,I5)
   15 FORMAT(32H ILLEGAL RESTRICTION TYPE AT ROW,2X,I5)
      END
```

```
      SUBROUTINE LPSOL(NOROW,NOCOL,IOPTS,ISOLTY,NOITER,OBJV)
      COMMON/  /DPM(60,180),RHS(60),INACT(60),ISACOL(60),IRWTY(60),
     1 OBJ(180),ZC(180)
      DIMENSION COLKEY(60)
      ISOLTY=1
      PRINT 2116
 2116 FORMAT(1X,'START L. P. SOLVE ')
      MXITER= 180
      NOITER=-1
  200 NOITER=NOITER+1
      JZCMX=0
      ZCMX=0.
      DO 101 J=1,NOCOL,1
      Z=0.
      DO 102 I=1,NOROW,1
      K=INACT(I)
  102 Z=Z+(DPM(I,J)*OBJ(K))
 2020 FORMAT(*ERROR CHECK*)
      ZC(J)=Z-OBJ(J)
      IF(ZC(J))103,101,101
  103 IF(ZC(J)-ZCMX)104,101,101
  104 ZCMX=ZC(J)
      JZCMX=J
  101 CONTINUE
      IF(JZCMX .GT. 0)GO TO 110
      IF(NOITER.GT.0)GO TO 112
      PRINT 10
   10 FORMAT(6H CHECK)
      RETURN
  112 X=-(9*(10**5))
      DO 115 I=1,NOROW,1
      J=INACT(I)
      IF(RHS(I).EQ.0.0) GO TO 114
      IF(OBJ(J) .EQ. X)GO TO 600
  114 IF(IRWTY(I).EQ.1)GO TO 115
      J=ISACOL(I)
      ZC(J)=ZC(J)+X
  115 CONTINUE
      OBJV=0.
      DO 120 I=1,NOROW,1
      K=INACT(I)
  120 OBJV=OBJV+(RHS(I)*OBJ(K))
      ISOLTY=0
      RETURN
  600 PRINT 60
```

```
 60 FORMAT(32H THERE ARE NO FEASIBLE SOLUTIONS)
    RETURN
110 IF(NOITER.LT.MXITER)GO TO 113
    PRINT 20
 20 FORMAT(28H NO ITERATIONS EQUAL MAXIMUM)
    RETURN
113 RMIN=990000000.
    NKR=0
    DO 150 I=1,NOROW,1
    IF(DPM(I,JZCMX))150,150,151
151 R=RHS(I)/DPM(I,JZCMX)
    IF(R-RMIN)155,156,150
155 RMIN=R
    NKR=I
    GO TO 150
156 DO 160 J=1,NOCOL,1
    R1=DPM(NKR,J)/DPM(NKR,JZCMX)
    R2=DPM(I,J)/DPM(I,JZCMX)
    IF(R2-R1)155,160,150
160 CONTINUE
    PRINT 30,NKR,I
 30 FORMAT(24H CYCLING HAS OCCURED AT,2X,I4,2X,I5)
    RETURN
150 CONTINUE
    IF(NKR.GE.1)GO TO 169
    PRINT 50,JZCMX
 50 FORMAT(28H UNBOUNDED SOLUTION,ACTIVITY,2X,I5)
    RETURN
169 INACT(NKR)=JZCMX
    DO 171 I=1,NOROW,1
171 COLKEY(I)=DPM(I,JZCMX)
    DO 170 J=1,NOCOL,1
170 DPM(NKR,J)=DPM(NKR,J)/COLKEY(NKR)
    RHS(NKR)=RHS(NKR)/COLKEY(NKR)
    DO 175 I=1,NOROW,1
    IF(I .EQ. NKR)GO TO 175
    RHS(I)=RHS(I)-(RHS(NKR)*COLKEY(I))
    IF(COLKEY(I) .EQ. 0)GO TO 175
    DO 176 J=1,NOCOL,1
    IF(DPM(NKR,J) .EQ. 0)GO TO 176
    DPM(I,J)=DPM(I,J)-(DPM(NKR,J)*COLKEY(I))
176 CONTINUE
175 CONTINUE
    GO TO 200
    END
```

```
      SUBROUTINE ROWSET(I,JCOL,IRHSTY,RHSV,ICARD,SUM)
      COMMON/  /DPM(60,180),RHS(60),INACT(60),ISACOL(60),IRWTY(60),
     1 OBJ(180),ZC(180)
      JCOL=JCOL+1
      INACT(I)=JCOL
      ISACOL(I)=JCOL
      IRWTY(I)=IRHSTY
      RHS(I)=RHSV
      IF(IRWTY(I).LT.1.OR.IRWTY(I).GT.3)CALL ERR(2,ICARD,SUM)
      IF(RHS(I).LT.0.0) CALL ERR(2,ICARD,SUM)
      DPM(I,JCOL)=1
      IF(IRWTY(I) .GT. 1)GO TO 202
      OBJ(JCOL)=0.
      GO TO 140
  202 OBJ(JCOL)=-(9*(10**5))
      IF(IRWTY(I).EQ.2)GO TO 140
      JCOL=JCOL+1
      DPM(I,JCOL)=-1
      OBJ(JCOL)=0.
  140 RETURN
      END
```

204 CARDS LISTED ON 14 PAGES

APPENDIX D

Machinery Cost Computer Program by Rotz (1981)

Machinery Cost Computer Program

This model was used to estimate the total annual cost of using the required implements in a crop production system. The input data required to execute the program varies depending upon the type of machine to be analyzed. These data include machine purchase price, age (row indicated new machine), power (in kw for tractor and combine usage), width (in m for implements), fuel type (1 = diesel, 2 = gasoline, 3 = petroleum gas, for tractor and combine usage), and speed (km/hr for implements).

The computer output of Rotz model provides the following information:

1. Ownership cost
2. Repair and maintenance
3. Fuel
4. Total present value
5. Average annual cost

MACHINERY COST COMPUTER PROGRAM

C. Alan Rotz

October, 1981

The machinery cost program computes the total costs of owning and operating farm machines, tractors and trucks. It includes the cost of capital, interest, insurance, shelter, repairs, maintenance, fuel, lubrication and labor. Inflation is modeled for all costs with a separate rate used on machinery, fuel and labor. Income tax deductions are modeled to include depreciation, interest, and operating costs along with an investment credit of 10 percent of the initial machine cost. Tax deductions are subtracted from the sum of all other costs to give a total cost. This cost is given as a total present value cost and as an equivalent annual cost.

Data Required by Program

When provided the appropriate input data, the machinery cost program can be used to analyze the costs of farm machines, tractors or automobiles. It can also be used to analyze the costs of several machines or a full crop production subsystem when supplied with data for all required machines. Input data required by the program includes:

Machine Type-	Numeric code shown in table below. Entry of 15 branches of the program to read your own repair and depreciation factors. Entry less than 15 allows use of stored factors.
Machine Age-	Age of machine in years. Zero indicates a new machine.
Wage Rate-	Hourly charge for operator labor.
New Price-	Dollar cost of the machine purchased new.
Power Rating-	Rated power of tractor (PTO kilowatt)
Annual Use-	Tractors - Average Annual use in hours. Machines - Average Annual use in hectares.
Fuel type-	1. = Diesel 2. = Gasoline 3. = Liquid Petroleum Gas.

Fuel Price-	Price per liter (decimal entered).
Machine Width-	Operating width of machine (meter).
Machine Speed-	Operating speed of machine in the field (kilometer per hour).
Hours per year-	Requested for automotive only. Average operation of vehicle in hours per year.
Kilometer per liter-	Requested for automotive only. Average fuel consumption.

Information Assumed by Program

Some parameters for the cost analysis are set internally by the program. These parameters include income tax information, inflation rates and loan information. The program assumes an income tax rate of 25 percent. All machines are depreciated for tax purposes over 5 years using the 1981, Accelerated Cost Recovery System.

Three inflation rates are used to model a separate inflation on machinery, fuel and labor. Machinery costs are inflated at the rate of 11 percent per year. Fuel inflation is set at 20 percent per year while labor is set at 9 percent per year.

The program converts all future costs to present value based upon a discount rate. This discount rate is set at 12 percent per year.

All machines are considered to be purchased with a loan with a 20 percent down payment. The term of the loan is set at 5 years with an interest rate of 12 percent per year.

Additional information is assumed for the field efficiency, repair factors and remaining value factors. These values were set to appropriate values based upon informationn found in popular text books on farm machinery management.

Implement	Type	E	RC1	RC2	RV1	RV2
Automotive	1	---	.055	1.8	.80	.84
Tractor	2	---	.025	1.6	.75	.87
Combine, Sp. Eq	3	.70	.140	1.8	.75	.88
Moldboard Plow	4	.85	.610	1.3	.70	.90
Disk Harrow	5	.80	.230	1.8	.70	.90
Chisel Implements	6	.80	.230	1.8	.70	.90
Row Planter	7	.65	.670	1.6	.70	.90
Drill	8	.60	.210	1.6	.70	.90
Sprayer	9	.60	.710	1.4	.70	.90
Mower-Conditioner	10	.85	.410	1.3	.70	.90
Rotary mower-Conditioner	11	.85	.260	1.6	.70	.90
Forage Equipment	12	.70	.330	1.3	.70	.90
Wagon	13	---	.300	1.6	.70	.90
Blower	14	---	.240	1.3	.70	.90

Use of Program

The machinery cost program is stored in a permanent file in the Cyber 750. It is in compiled form for economical access and use in a permanent file name ROTZMACHCOST. It can be used by attaching a work file to the permanent file and executing the work file. An example job is shown below.

For Interactive Use	For Batch Use
(Log in)	(PN card)
CONNECT, INPUT, OUTPUT.	(Job card)
PROMPT=ON.	(PW card)
ATTACH,W,ROTZMACHCOST.	ATTACH,W,ROTZMACHCOST.
W.	W.
.	7/8/9
.	.
.	.
.	.
(data cards)	(data cards)
.	.
.	.
.	.
99.	STOP
(Log out)	6/7/8/9

Data cards for the program can be given in any format, however, the numbers on the cards must be in proper order. The proper order is dependent on the type of machine analyzed as given below. Two data cards are required for each machine analyzed unless the machine is purchased used. For a used machine a third data card is needed to give the purchase price and use on the machine.

Form for Input Data

The input data required to execute the program varies depending upon the type of machine to be analyzed. There are three major forms for the data to model the costs of either a tractor, farm machine, or truck. These data forms are listed below.

TRUCK OR AUTOMOBILE (Type 1)

(1) Machine code, Name
(2) New cost, Age, km/yr, km/liter, Insurance cost
(3, If used) Purchase price, kilometers on vehicle

TRACTOR OR SELF-PROPELLED MACHINE (Type 2 or 3)

(1) Machine code, Name
(2) New cost, Age, Power, Annual use, Fuel type
(3, If used) Purchase price, Hours on machine

IMPLEMENTS (Type 4 to 5)

(1) Machine code, Name
(2) New cost, Age, Annual use, Width, Speed
(3, If used) Purchase price, Hours on machine

CHANGE OF PARAMETERS

Data can also be used to change parameters which have been set internal in the program. Parameters can be changed by using code 90. or 95. as shown.

90. DATA Fuel price, Wage rate, Work time ratio, Insurance & shelter rate, Income tax rate, Print level.

95. DATA Down payment, Interest rate, Discount rate, Machine Inflation, Labor Inflation

END OF DATA

Data is required to specify the end of a system of machines by assigning a code of 0. and a code of 99. should be specified at the end of all systems.

```
**************************************************************************
*                                                                        *
*                        MACHINERY COST PROGRAM                          *
*                            C. ALAN ROTZ                                *
*                              9/15/81                                   *
*                                                                        *
**************************************************************************
      PROGRAM SYSECON(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON /MEC/ NN,DPAY,IR,A,G,B,C,FP,WAGE,WTIME,TISR,TRI,PRNT
      REAL TOWN(200),TREP(200),TFUEL(200),TLAB(200),AC(200),PVC(200)
     +,Z(200),IR
 5    TPVC=0.0
      I=0
10    READ (5,100)T,Z1,Z2
      IF(T.EQ.0) GO TO 50
      IF(T.EQ.90) READ *,FP,WAGE,WTIME,TISR,TRI,PRNT
      IF(T.EQ.95) READ *,DPAY,IR,A,G,B,C
      IF(T.EQ.90.OR.T.EQ.95) GO TO 10
      IF(T.EQ.99) STOP
      I=I+1
      Z(I)=Z1
      CALL MECON (T,Z1,Z2,TOWN(I),TREP(I),TFUEL(I),TLAB(I),AC(I),PVC(I))
      GO TO 10
50    WRITE(6,110)
      WRITE(6,120)
      WRITE(6,130)
      WRITE(6,120)
      DO 60 K=1,I
      WRITE(6,140) Z(K),TOWN(K),TREP(K),TFUEL(K),TLAB(K),PVC(K),AC(K)
60    TPVC=TPVC+PVC(K)
      WRITE(6,120)
      WRITE(6,150)TPVC
      GO TO 5
C FORMAT STATEMENT
100   FORMAT(F3.0,A10,A10)
110   FORMAT(//,25X,"PROJECTED SYSTEM COSTS")
120   FORMAT(1X,12(6H------))
130   FORMAT(5X,"COST",4X,"OWNERSHIP",2X,"REPAIR",6X,"FUEL",
     +5X,"LABOR",5X,"TOTAL",4X,"AVERAGE",/,5X,"TYPE",6X,"COSTS",
     +4X,"&MAIN.",26X,"PV",6X,"ANNUAL")
140   FORMAT(1X,A10,6F10.0)
150   FORMAT(3X,"PRESENT VALUE OF SYSTEM COSTS: $",F10.0)
      STOP
      END
      SUBROUTINE MECON (T,Z1,Z2,TOWN,TREP,TFUEL,TLAB,AC,PVC)
      COMMON /MEC/ NN,DPAY,IR,A,G,B,C,FP,WAGE,WTIME,TISR,TRI,PRNT
      REAL NCOST,MILPY,MPG,INS,INT,LABOR,ACRF(5),IR
      DIMENSION E(15),RC1(15),RC2(15),RV1(15),RV2(15),FFL(3),FFH(3)
```

```
C
C  INITIAL INPUT DATA
       DATA E/1.,1.,.7,.85,.8,.8,.65,.6,.6,.85,.85,.7,1.,1.,1./
       DATA RC1/.055,.025,.14,.61,.23,.23,.67,.67,.71,.41,.26,.33,
      +.3,.24,.0/
       DATA RC2/1.8,1.6,1.8,1.3,1.8,1.8,1.6,1.6,1.3,1.3,1.6,1.3,1.6,1.3,
      +1./
       DATA RV1/.8,.75,.75,.7,.7,.7,.7,.7,.7,.7,.7,.7,.7,.7,.7/
       DATA RV2/.84,.87,.88,.9,.9,.9,.9,.9,.9,.9,.9,.9,.9,.9,.9/
       DATA ACRF/.15,.22,.21,.21,.21/
       DATA FFL/.169,.25,.26/,FFH/.283,.41,.49/,NN/10/,TRI/.25/,WTIME/.8/
       DATA TISR/.01/,G/.11/,A/.12/,B/.2/,C/.09/,DPAY/.2/,NM/5/,IR/.12/
       DATA FP/.32/,WAGE/4.25/,PRNT/2.0/
       EFC=1.0
       TARO=OLDUSE=PVC=OPC=TOWN=TREP=TFUEL=TTD=TLAB=0.0
       IF (T.EQ.15) READ *,E(T),RC1(T),RC2(T),RV1(T),RV2(T)
       IF (T-2) 20,25,30
C
C  INITIAL SET UP FOR AUTOMOBILE
20     READ *,NCOST,AGE,MILPY,MPG,INS
       FUEL=MILPY/MPG*FP
       USE=MILPY/48.
       GO TO 40
C
C  INITIAL SET UP FOR TRACTOR
25     READ *,NCOST,AGE,HP,USE,FT
       FUEL=FP*HP*USE*(FFL(FT)*(1.-WTIME)+FFH(FT)*WTIME)
       GO TO 40
C
C  INITIAL SET UP FOR MACHINERY
30     IF(T.EQ.3) GO TO 25
       IF (T.EQ.13.OR.T.EQ.14) READ *,NCOST,AGE,USE
       IF (T.EQ.13.OR.T.EQ.14) GO TO 35
       READ *,NCOST,AGE,ACRE,W,S
       EFC=W*S*E(T)/10.0
       USE = ACRE/EFC
35     FUEL = 0.0
40     RVO = NCOST
       IF (AGE.EQ.0) GO TO 45
       READ *,PCOST,OLDUSE
       RVO = PCOST
       TARO = NCOST*RC1(T)*(OLDUSE/1000.)**RC2(T)
45     J = AGE
       END = AGE + NN
       RV = NCOST*RV1(T)*RV2(T)**END
       IF(PRNT.EQ.1)WRITE(6,100)Z1,Z2
       IF(PRNT.EQ.1)WRITE(6,110)
       IF(PRNT.EQ.1)WRITE(6,120)
       IF(PRNT.EQ.1)WRITE(6,110)
C
C   LOAN COST
       DPAYM = DPAY*RVO
       PAY = (RVO-DPAYM)*(IR*(1.+IR)**NM)/((1.+IR)**NM-1.)
       MORT = PAY*NM
       DO 50 I = 1,NN
       J = J + 1
```

```
C
C     CAPITAL COST
        CAP = PAY
        IF(I.GT.NM)CAP = 0.
        IF(I.EQ.1)CAP = CAP + DPAYM
        IF(I.EQ.NN) CAP = CAP - RV*(1.+G)**NN
C
C     OWNERSHIP COSTS
        TIS = TISR*NCOST*(RV1(T)*RV2(T)**J+.5)*(1.+G)**I
        IF(T.EQ.1)TIS = TIS + INS*(1.+G)**I
        TOWN = TOWN + (CAP+TIS)/(1.+A)**I
C
C     OPERATING COSTS
        TAR = NCOST*RC1(T)*((OLDUSE+USE*(J-AGE))/1000.)**RC2(T)
        REP = (TAR-TARO)*(1. G)**I
        TARO = TAR
        TREP = TREP + REP/(1.+A)**I
        FUELL = 1.15*FUEL*(1.+B)**I
        TFUEL = TFUEL + FUELL/(1.+A)**I
        LABOR = 1.1*WAGE*USE*(1.+C)**I
        IF(T.GT.3)LABOR = 0.
        TLAB = TLAB + LABOR/(1.+A)**I
C
C     INCOME TAX DEDUCTIONS
        D = 0.0
        IF(I.LT.6) D = ACRF(I)*RVO
        MORT = AMAX1(0.,MORT-PAY)
        IT = IR*MORT
        TD = TRI*(D+IT+TIS+REP+FUELL+LABOR)
        IF(I.EQ.1.AND.TRI.NE.0)TD = TD + .1*RVO
        TTD = TTD + TD/(1.+A)**I
C
C     TOTAL COST
        TOTAL = CAP+TIS+REP+FUELL+LABOR-TD
        PVC = PVC + TOTAL/(1.+A)**I
        OPC = OPC + (TOTAL-CAP+IT)/(1.+A)**I
        IF(PRNT.EQ.1)WRITE(6,130)I,CAP,TIS,REP,FUELL,LABOR,TD,TOTAL
 50.    CONTINUE
C
C     PRESENT VALUE COSTS
        AC = PVC*(A*(1.+A)**NN)/((1.+A)**NN-1.)
        AOPC = OPC*(A*(1.+A)**NN)/((1.+A)**NN-1.)
        IF(PRNT.EQ.1)WRITE(6,110)
C
C     FORMAT STATEMENTS
 100    FORMAT(//,1X,"PROJECTED COSTS OF ",A10,A10,/)
 110    FORMAT(1X,12(6H------))
 120    FORMAT(1X,"YEAR",2X,"CAPITAL",2X,"INSURANCE",2X"REPAIRS",
       +4X,"FUEL",5X,"LABOR",3X,"INCOME TAX",2X,"TOTAL",/,16X,
       +"& SHELTER",2X,"& MAIN.",3X,"& LUB.",12X,"DEDUCTIONS")
 130    FORMAT(I3,7F10.0)
 190    FORMAT(F3.0,A10,A10)
        RETURN
        END
```