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THE FEASIBILITY OF ON-FARM ETHANOL PRODUCTION IN MICHIGAN: A LINEAR PROGRAMMING APPROACH

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Mark Francis Jackson

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J. Roy Black
Major professor

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THE FEASIBILITY OF ON-FARM ETHANOL PRODUCTION IN MICHIGAN: A LINEAR PROGRAMMING APPROACH

By

Mark Francis Jackson

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ABSTRACT

THE FEASIBILITY OF ON-FARM ETHANOL PRODUCTION IN MICHIGAN: A LINEAR PROGRAMMING APPROACH

By

Mark Francis Jackson

Substantial interest has recently been generated in small-scale on-farm ethanol production primarily due to uncertainties concerning external petroleum supplies and rising real liquid fuel costs. The question of the economic feasibility of such a venture has been approached from a variety of angles generally relying on partial budgeting schemes. It is the purpose of this theses to address the viability of on-farm ethanol production from a whole farm context in order to more accurately depict the interactions taking place within a farming system which includes an energy production subsystem.

A linear programming model was used to structure a farm located in the eastern thumb area of Michigan. By using the model to determine the breakeven capital expenditures for different ethanol production units, it was established that within the existing technological and economic environment, on-farm ethanol production will not be profitable except in those cases where an abundance of surplus labor affords the farmer the time not only to run the subsystem, but to construct portions of the unit as well.

To my mate, Karen, and crew,
Dylan and Tristan, who have
taught me that love, like the
wind, is free. The more you
give the more you receive.

ACKNOWLEDGMENTS

I owe a great deal of thanks to Milton Ed Rister for painstakingly guiding me through the mechanics of linear programming. I would have hated to do it without his selflessness. Phil Savoy was a big help in developing the machinery complement for the cropping subsystem of the whole farm model. Also, thanks is owed my committee members, John Waller and Bill Stout, for their direction and encouragement. Last, but hardly least, J. Roy Black, my thesis advisor and friend, deserves credit for teaching me the meaning of perseverance. From the beginning he made me suspect that alcohol belonged not in the fuel tank, but in the bottom desk drawer of every graduate student forced to cope with eccentric academicians.

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CHAPTER I

INTRODUCTION

1.1 Why Alcohol?

Liquid fossil fuels are a nonrenewable energy resource; use today precludes use tomorrow. After three decades of declining real liquid fuel prices, a result of oil discoveries in the Middle East, improved oil recovery technology techniques, low real interest rates, and the October 1973 Arab oil embargo led to a rapid revision of our perceptions about energy. The term "crisis" was used as though an impending disaster were on the horizon.

The extent of the power of the Organization of Petroleum Exporting Countries (OPEC) was realized for the first time since its inception in the 1960s, even though the embargo did not involve all members. No longer able to rely on the ability to bargain with other members of a less unified OPEC, concern over the price and security of energy resources became widespread. An immediate search for alternatives began.

Statements of the form:

> As gasoline creeps toward $1.20 a gallon with no end to the upward spiral in sight, the economic gaps start to close, new technology comes of age, and alternative fuels begin getting a great deal of attention.... One of the more interesting alternatives, with the fewest attendant problems, is alcohol.... The advantage of biomass-alcohol fuels are enormous. The feedstock is a renewable resource as long as U.S. soil will grow plants, there will be no danger of a shortage of the raw material.[1/]

[1/] Newhouse News, 1979.

became common. Farmers caught in a cost-price squeeze searched for means to alleviate the pressure. Some saw ethanol production as a way of increasing supplies of liquid fuel, increasing commodity prices, and as a way to "save" rural America:

> The United States has been bogged down in "burdensome" surpluses from farm products for years, the USDA will tell you, and the main "farm problem" has been how to get rid of them. These surpluses have been blamed for low crop prices, rural poverty, and for farmers leaving the land to swell the cities' welfare and unemployment ranks. With the mass exodus, Rural America is dying. There is no reason for Small Town America to exist after the farmers leave the land.[2/]

Whatever the motivation, farmers are interested in the prospects for ethanol production, but concern has arisen over the economic viability of farm scale ethanol production. The objective of this study is to assess the feasibility of such a venture in Michigan.

1.2 Nature of the Research

Farmers are interested in on-farm ethanol production for reasons ranging from patriotism to profits. Three principal reasons emerge: (1) the establishment of an additional outlet for their commodities (e.g., corn) as a feedstock in ethanol production; (2) a degree of liquid fuel self-sufficiency; and (3) increased profits. The efficacy of on-farm ethanol production, in the context of these objectives, is the subject of this study.

Four questions form the basis of the inquiry:

(1) What is the maximum amount a farmer can afford to invest in an ethanol production system given a particular capacity and commodity prices?

[2/] Nellis, 1979.

(2) What is the impact of the size of the ethanol production system on labor and operating costs and the maximum amount a farmer can afford to invest in an ethanol production system?

(3) What ethanol production capacity will be needed to provide energy self-sufficiency?

(4) What is the sensitivity of the maximum amount a farmer can afford to invest in an ethanol production system to alternative gasoline and diesel prices, corn prices, and wage rates?

The procedure will be to design the ethanol production system using engineering economic techniques. A whole farm budgeting approach will be used to examine the relationship among farm enterprises when an ethanol production subsystem is included. The "thumb" area of Michigan is considered because it possesses the potential to provide an adequate feedstock supply and supports a fed cattle population large enough to utilize substantial amounts of the co-product, distillers grains with solubles. A 750 acre farm with 1,000 head one-time feedlot capacity is analyzed since it is common in the area and is large enough to support co-product use from an ethanol production subsystem.

The approach taken establishes an environment conducive to the success of on-farm ethanol production. If on-farm ethanol production is not economically feasible in a favorable setting, it will not be feasible on a small-scale in Michigan.

1.3 Structure of the Study

The structure of the study is as follows. Ethanol fuels and the nature of on-farm ethanol production are discussed in Chapter II. The linear programming (LP) model used in the whole farm budgeting approach is outlined in Chapter III with emphasis on the establishment of the cropping sequence, ration formulation, and ethanol production assumptions. The farm is divided into its three subsystems: (1) cropping; (2) beef feeding; and (3) ethanol production. Model results are presented and discussed in Chapter IV. Policy implications and the area of applicability are discussed in Chapter V.

CHAPTER II

ETHANOL PRODUCTION: PROBLEMS AND POTENTIAL

2.1 Introduction

The debate over the efficacy of ethanol[1/] (ethyl alcohol) production has taken place in an environment of much controversy and limited information. Ethanol production in the U.S. is determined by feedstock availability, production capacity and technology, societal acceptability, and economic feasibility. The first three issues are the basis for the discussion contained in this chapter. On-farm economic feasibility will be dealt with in the remainder of the study.

An overview of the potential for ethanol production in the U.S. will be discussed in the first section of this chapter. It will include an analysis of the gasohol and low proof ethanol questions. Considerations raised by ethanol production will be addressed in the second section. Farm scale ethanol production is examined in the last section with focus upon farmer choices, the physical description of an ethanol production system, and the utilization of both the ethanol and by-products.

[1/] Ethanol (C_2H_5OH) is often referred to by the generic term alcohol since its chemical formula is related to other alcohols by following the general $C_nH_{2n+1}OH$ pattern. Ethanol differs from methanol (CH_3OH) in that it has one more carbon molecule.

2.2 U.S. Potential for Ethanol Production

Four classes of raw materials for alcohol production are: (1) hydrocarbon gases (e.g., coal gas, natural gas derivatives, waste gases); (2) saccharine materials (e.g., molasses, sugar beets and cane, fruits); (3) starch containing materials (e.g., cereal grains, potatoes); and (4) cellulosic materials (e.g., wood, leafy plants, paper industry by-products).

Both ethanol and methanol can be used as a liquid fuel for internal-combustion engine. Ethanol is more attractive than methanol for fuel use because it is less corrosive and toxic as well as being more readily produced from a variety of renewable feedstocks. Examples of the various feedstocks used for ethanol production include feed and food grains, sugar beets and cane, potatoes, artichokes, and food processing wastes. Grasses can be processed to produce ethanol, but the economics of this conversion procedure preclude the use of grasses as a feedstock.

The first class of raw materials, gases, are usually associated with nonrenewable energy sources but can also be the product of the anaerobic digestion of organic matter. Methane produced in this manner is an end product in itself and would not be converted to methanol. The liquefaction of gases from nonrenewable sources will not be considered in this study.

The sugar containing or saccharine materials most readily break down to monosaccharides thereby simplifying the conversion process. Sugar crops comprise a very small proportion of the total U.S. cultivated acreage; sugar cane is infinitesimal and sugar beets make up less than .3 percent. If alcohol production from sugar crops is profitable, their acreage will expand as energy crops, especially since their per acre potential for alcohol production exceeds all grain crops (see Table 2-1).

TABLE 2-1. Estimated Alcohol Yields Per Acre for Selected Crops

Crop	Yield (Unit/Acre)[a/]	Conversion	Alcohol Yield (Gal/Acre)
Corn	109.4 bu	2.6 gal/bu	285.74
Wheat	34.2 bu	2.6 gal/bu	88.92
Oats	54.4 bu	1.05 gal/bu	57.12
Potatoes	272 ton	1.4 gal/cwt	380.8
Sugar Beets	19.6 ton	27 gal/ton	529.2
Sugar Cane		15 gal/ton	626
Hay	2.39 ton	30 gal/ton	71.7

[a/] U.S. averages, 1979, Crop Production, United States Department of Agriculture, July 1980.

Currently in the U.S. the greatest potential for ethanol production lies in the last two classes of raw material, starch containing and cellulosic materials. As has already been alluded to in the case of the grasses, the sugar needed for ethanol production is not as readily available in these materials as in the saccharines. They must first undergo hydrolysis to break the starch and cellulose down to polysaccharides which subsequently break down to fermentable monosaccharides. Simple enzymatic action is employed to reduce the starches but complicated procedures utilizing acidic reactions are required to break down cellulose. The two have the same formula, $(C_6H_{10}O_5)_n$ but because of its β glucosidic linkage, cellulose is extremely stable.[2/]

Existent technology is not efficient in the hydrolysis of cellulose. Although respectable yields per ton are possible from hay and crop residue, the energy expenditure needed to support these conversion rates is unjustifiably high. Unless there is a technological breakthrough, these materials seem best suited for energy conversion by direct combustion or natures convertor, the ruminant animal.

Starch containing material such as feed and food grains, offer the greatest potential for use as an agricultural feedstock due to their relative ease of conversion and large supply. Of the grains, corn is the most plentiful accounting for over 55 percent of U.S. grain production and over 80 percent of Michigan's 1979 grain output.[3/]

Annual U.S. gasoline consumption by surface vehicles was just below 100 billion gallons in 1980. On a BTU basis this volume is equal to 121×10^H kBTU.[4/] If the same energy content were to be supplied by ethanol, 143 billion gallons of ethanol would be required. With a conversion ratio of 2.6 gallons of ethanol per bushel of corn 55 billion bushels of corn would be needed for ethanol production. This corn requirement is seven times the total U.S. production reported for the 1979/80 crop year.[5/]

[2/] Ogden, 1980.

[3/] MDA, 1980.

[4/] 1 kBTU = 1000 BTU and the energy content of gasoline is 121,000 BTU.

[5/] USDA, 1981.

If one were to plant corn for fuel on all of the 214 million acres planted to corn grain, wheat and soybeans in the 1979/80 crop year and managed the national average of 109.7 bushels per acre there would still be a short fall of 23.5 billion bushels of corn or 83 billion gallons of ethanol. It is readily apparent that U.S. motor fuel needs will not be met by ethanol production from grains even with a most radical shift in fuel consumption and grain production. Still, more limited applications of fuel ethanol are being pursued; gasohol and ethanol use of low proof ethanol are foremost among these applications.

2.2.1 Gasohol

Most of the U.S. interest in ethanol as a fuel has centered around a mixture of alcohol and gasoline to extend our petroleum supply and provide a substitute for lead as an octane booster. Gasohol is a 10 percent alcohol and 90 percent regular, unleaded gasoline mixture; it requires no major adjustments of engines but does necessitate the use of anhydrous ethanol to prevent phase separation.

By 1985 the use of lead as an octane booster in automobile fuel is to be phased out due to its detrimental environmental impact. The octane rating, a measure of the antiknock properties of a liquid motor fuel, of ethanol is higher (over 100) than gasoline (ranges from 87 to 93) and thus, has a unique advantage when it is blended as gasohol. The emissions of gasohol are considered relatively environmentally benign offering itself as a plausible substitute for lead. In addition to avoiding the undesirable emissions associated with the use of lead, gasohol has also been shown to emit lower levels of carbon monoxide (CO) and hydrocarbons (HC), although nitrogen oxide (NO_x) may increase.[6/]

With the cooperation of the oil refineries, the octane of the gasoline blended to gasohol can be lowered to exactly compensate for the octane boosting properties of the ethanol. If this is done, there is an energy savings of 88,000 to 150,000 BTU per barrel of oil refined. This amounts to a savings of 0.27-0.45 gallons of gasoline equivalent for each gallon of ethanol used if the energy savings are attributed solely to the ethanol.[7/]

In addition to the technical problem of phase separation mentioned earlier, there can be a problem with vapor lock at high summer temperatures as well. Although the potential exists when using gasoline alone, it is more likely to happen with gasohol because ethanol has a relatively high blending vapor pressure with gasoline. Another concern arises because alcohol is such a good solvent. Filters can become clogged with resin and gum dissolved from engines that had been running on gasoline alone. In the extreme, gasohol may remove oil film from the cylinder walls resulting in greater cylinder and ring wear.[8/]

The U.S. Government under the Carter administration actively promoted a nationwide gasohol program. An incredible increase in production capacity would be necessary to achieve the program's goal of 100 billion gallons of gasohol each year. U.S. ethanol production capacity for

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[6/] Litterman, et al., 1978.

[7/] U.S. Congress, 1979.

[8/] Meekof, et al., 1980.

gasohol is in the neighborhood of 100 million gallons per year with 50 percent produced by the Archer-Daniels-Midland (ADM) plant in Decatur, Illinois.

With an annual corn production ranging between 6.3-7.7 billion bushels, a U.S. gasohol program demanding 10 billion gallons of anhydrous ethanol would use 60 percent of the nation's corn production. Even when DDGS production and acreage released from soybean production are taken into account the feed and food markets will still feel significant effect.[9/] The result would be a substantial increase in feed and food grain, oilseed and livestock prices.

A detailed study of all the interactions of such a large scale gasohol program using corn as a feedstock would require a separate study in itself. Even a rough assessment is enough to demonstrate that corn would not be employed as the sole feedstock in a national gasohol program. However, it is conceivable that a combination of feedstocks could provide the requisite 10 billion gallons of alcohol for gasohol.

2.2.2 Low Proof Ethanol

Despite the inability to mix low proof (proof is a measure for alcohol content; proof ÷ 2 = percent) ethanol with gasoline, the production of less than 100 percent ethanol is appealing for several reasons. Primarily, there is a considerable energy savings during distillation by not processing to achieve an anhydrous product. It takes a comparable amount of energy to refine 130 proof alcohol to 190 proof as was used to

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[9/] Meekof, et al., 1980.

acquire the first 130 proof product.[10/] Furthermore, it is not possible to obtain pure anhydrous ethanol without the inclusion of a "drying" step performed after normal distillation is complete.

The conventional method for drying ethanol has been the addition of a third chemical such as benzene or cyclohexane as a solvent. An azeotrope, or constant boiling temperature mixture, is formed of the three compounds, benzene, ethanol, and water. Subsequently the azeotrope is removed by distillation or solvent extraction leaving 100% ethanol.

Molecular sieves are being developed as a possible replacement for solvent extraction but an increasing amount of energy is still used to remove a decreasing degree of moisture from the ethanol. Molecular sieves are being used in smaller scale (below 5 million gallons annual production) operations because of their relative low investment requirements. A molecular sieve is a membrane permeable to water but not ethanol. Water is "trapped" within the membranes as low proof ethanol is passed through a structure containing the minute sieves. Once the sieves are saturated precluding the removal of any more moisture they must be dried for reuse.

The distillation of lower proof ethanol saves energy and simplifies the process considerably. For the farmer producing his own fuel ethanol, this is an important consideration. The small scale producer will be sensitive to the lower capital requirements as well as the time to be saved by eliminating the additional purifying steps.

[10/] Geiger, et al., 1981.

Energy independence is an objective of some of the farmers considering use of low proof ethanol. Less than pure but greater than 140 proof ethanol can replace gasoline in engines with moderate modifications. The performance of the fuels is proportional to their energy or BTU content (i.e., the energy value in 1.8 gallons of 160 proof ethanol is equal to the energy value in 1 gallon of gasoline). In theory, water in low proof ethanol will enhance its performance or power per BTU. In MSU testing, 180 proof ethanol was shown to provide more power per BTU than either 200 proof ethanol or gasoline. Below 180 proof, power began to drop; 160 proof ethanol produced 5 percent less power than gasoline.[11/] Work remains to be done to ascertain the effect of water on engine wear.

Even so, the replacement of diesel compression ignition engines with gasoline spark ignition engines will limit farmers in their ability to utilize ethanol fuel. Although it is possible, the alterations required by the compression ignition engine makes the interchange between diesel and ethanol improbable. Dual fueling systems that blend low proof (as low as 100 proof) ethanol with diesel just before introduction to the combustion chambers are being tested, but again, the effect on engine wear need further investigation.

2.3 Issues Surrounding Ethanol Production

There has been considerable disagreement over possible repercussions of a nationwide surge in ethanol production. Disputes embroil environmental and moral issues as well as technical arguments of feasibility.

[11/] MSU, 1981.

Controversy over the procurement of the elemental feedstock finds opponents and proponents of ethanol production spread over a wide spectrum of convictions. Sentiments range from those who feel lands now in the national set aside programs would be sufficient to supply the needed grain to persons equally adamant in their belief that any increase in the pressures demanded of the land by growing fuel crops would render irrepairable damage to the ecosystem. These examples represent the extremes. In between lie more pragmatic concerns that can be labeled food versus feed versus fuel, liquid fuel balance, and land use considerations.

2.3.1 Food Versus Feed Versus Fuel

Corn is a good prospect as a feedstock for ethanol production because of its high energy (starch) content. During the conversion process the form of this energy is changed from a solid starch to a liquid fuel. In its solid form the energy is available, through digestion, to humans and livestock. In a liquid state the energy can be used in internal combustion engines. This presents a tradeoff, and consequently establishes an opportunity cost for removing the starch from corn for alcohol production.[12/]

There is little disagreement over the idea that the food system will in some way be affected by diverting grains to fuel production. The major conflict arises from debate concerning which actors will be involved and the extent to which the repercussions will be felt. Those

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[12/] Tyner, 1980.

who proclaim that the hungry masses of the underdeveloped world will suffer from decreased grain shipments are met with arguments purporting the benefits of shipping a concentrated protein food source in the form of distillers dried grains (DDGS). Both arguments are weak in substance.

First of all, as was learned during the Green Revolution, palatability and custom play a very large role in the acceptance of new foodstuffs. Under these circumstances, the assimilation of DDGS into local diets in developing countries is dubious. Secondly, as Francis Moore Lappe pointed out in her book, Food First, the world hunger situation does not stem so much from a lack of production as from inadequate distribution of existing food supplies.[13/] Incompetence in the political and physical infrastructure of the lesser developed countries deserve much of the blame for the inefficiency of previous world food programs. Should the DDGS reach the hungry of the world it would have the same low protein quality as corn; deficient in lysine, tryptophan and to a lesser extent methionine and cystine. Concentrating the protein content does not improve the protein quality.

Finally, 1979 figures show that less than 8 percent of corn production was used for food and beverage while 60 percent was used domestically for animal feed and another 30 percent was exported primarily to the industrial world for livestock use. In fiscal year 1979, almost all of the $32 billion of U.S. agricultural exports represented commercial sales for dollars. Only $1.5 billion moved under Public Law 480 and Agency for International Development (AID) programs.

[13/] Lappe and Collins, 1977.

Principally, it was this last little recognized fact that prompted Wallace E. Tyner to observe the following:

> "Corn is the grain most often discussed as a feedstock for alcohol production in the U.S.... Since corn is a feed grain and not consumed directly by humans in large amounts a more correct characterization of the food/fuel issue would be the food/feed/fuel issue. The use of large amounts of corn for ethanol production would tend to increase corn prices and lead to reduced use of corn for animal feed. The corn price increase would lead to higher meat, dairy, and poultry product prices which would, in turn, lead to reduced consumption of these products....From this perspective, the major impact of a large U.S. grain alcohol program would be on people (throughout the world) who consume animal products."14/

2.3.2 Liquid Fuel Balance

Impetus for advancing an ethanol fuel program is easing U.S. dependence on foreign oil and gas by utilizing a renewable domestic liquid fuel source. The capacity of this endeavor depends on the amount of liquid fuel that is used to produce a given amount of ethanol. This is referred to as the "liquid fuel balance." Tables 2-2 and 2-3 delineate energy required in the production of corn and in the production of ethanol from corn. It is evident that should liquid fuels be used throughout the corn and ethanol production processes up to a 0.3 gallon (gasoline equivalent) liquid fuel reduction could result, depending on the technology used. On the other hand, by using solid fuels wherever possible in the production of ethanol, a 0.7 gallon gain in the liquid fuel balance could be realized. This figure is subject to further change when

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14/Tyner, 1980.

TABLE 2-2. Energy Used in Corn Production

Operation	Percent of Energy Used
Tillage	7.7
Fertilizer	53.2
Herbicide and Pesticide Use	3.0
Harvest	2.5
Drying	28.0
Transportation	5.6

Sources: CAST (1977); DOE (1979); and USDA (1980). Percentages vary with soil management group, cultural practices, and management.

TABLE 2-3. Energy Balance in the Production of One Gallon of Ethanol from Corn[a]

Task and/or Product	Energy (gallon gasoline equiv.)	
	Debit	Credit
Corn Production	.30-.40	
Ethanol Production, including drying DDGS[b]	.35-.90	
Ethanol (1 gallon)[c]		.80-.90
By-Product Credit[d]		.11-.12
Energy Saved in Refining by Octane Enhancement		.06

[a] Sources: Hawley, Martin C., J. Roy Black and A. Grulke. "Ethanol for Gasohol: Production and Economics," Feedstuffs, March 30, 1981.

[b] Vendors of new technology claim 0.35-0.40 is feasible with current energy recovery techniques. Liquid fuel use (gasoline, diesel, natural gas) is near zero for this phase if coal or wood is used.

[c] Assumes a 2 to 3% increase in thermal efficiency of combustion when ethanol is combined with gasoline at low rates.

[d] Energy released by now growing and processing a "protein supplement" comprised of 52% soybean meal: 48% corn. The supplement has the same crude protein and energy as DDGS.

alternative methods of cultivation are considered in corn production. This exercise illustrates the sensitivity of the energy balance dilemma to the accounting procedure. It also demonstrates that liquid fuel gains are possible but success may be contingent upon developing and accepting complementary grain and ethanol production procedures.

2.3.3 Land Use Considerations

If alcohol production is to bid grain away from other uses, it will have to be because it is more profitable for the farmer to supply it. This incentive would lead to an increase in the cultivation of energy crops (i.e., corn). Such reliance upon a monoculture increases the use of fertilizers, pesticides and herbicides. These products are, for the most part, petroleum based. Their use further depletes our petroleum supplies and possibly causes a dependence of the soil on their continued exploitation. To gain a notion of the magnitude of the petroleum used, it would take .5 percent of the U.S. production of natural gas to fertilize 50 million acres of corn at current application rates.[15/] The premature aging of streams and other damage to the aquatic ecosystems caused by the leaching of these nutrients to surface and ground water should application rates become excessive brings on further concern.

Soil erosion would also be hastened by intensifying the production of energy crops. Generally, annual crops are more erosive than perennials and row crops more so then close-grown crops thereby making the most attractive feedstock from a yield and cost standpoint, corn, also one of the most erosive. For every bushel of corn harvested from the hillside

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[15/] U.S. Congress, 1979.

fields in Iowa, two bushels of topsoil are lost; one and a half bushels are washed away and one half bushel is blown away. Only half of the two feet of the top soil found beneath native sod remains in cultivated fields.[16/] Conserving methods of cultivation could reduce this loss but the profit motive may make their use rare. True, this problem already exists, but increased economic pressure to produce energy crops will, if anything, aggravate the situation.

Removal of biomass for alcohol conversion or to directly fire the ethanol production unit could further accelerate erosion and soil depletion. The extent of these possibilities depends on the tillage practices and crop rotations as well as the soil type and slope of the land. No-till practices allow more of the residue to be removed, but they also require the applications of more pesticide and herbicides and are useful on a very limited basis depending upon soil type. Some of the residue can be removed from some of the land with no harmful effects but a careful study of the above mentioned considerations is an essential prerequisite.

2.4 Farm Scale Ethanol Production

Farm scale ethanol production can range from a few thousand gallons per year upward toward several hundred thousand gallons per year. Farm scale is used to describe those ethanol production systems operated as a subsystem of a single farming enterprise. The size of such an operation is determined by the individual farmer's personal preferences and resource availability within the bounds of existing regulation.

[16/] Kramer, 1979.

2.4.1 The Farmer's Choice

There are at least three possible scenarios of farm scale ethanol production. They are: (1) to produce anhydrous ethanol (200 proof) for personal use and/or resale as a component for gasohol; (2) to produce 185 to 190 proof ethanol for resale to a centrally located "drying" facility[17/] for further refinement to anhydrous ethanol; and (3) to produce a low proof ethanol for direct on farm use in modified engines.

The production of anhydrous ethanol on the farm is unlikely due to a substantial increase in the capital and technical expertise requirements of removing the last few percentage points of moisture. Economies of scale come into play to make commercial production of 200 proof ethanol feasible. A major technological breakthrough is needed before small scale operations will be able to economically produce an anhydrous product.

Ethanol at 95.6% forms a constant boiling mixture or azeotrope which precludes the removal of the remaining water using conventional distillation methods. Once farmers reach this point in the production of ethanol it may be best to transport this product to a central refinement location. This, of course, necessitates the presence of considerable transportation and handling infrastruction on and off the farm. Furthermore, one cannot underplay the importance of a functioning and efficient regulatory system which effectively controls the movement of the ethanol within minimum hindrance to efficiency.

Finally the product and use of low proof ethanol on the farm is attractive from the standpoint of minimizing the handling and transportation

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[17/] A drying facility would remove the moisture remaining after conventional distillation. This step requires specific equipment which is essential to economies of scale.

of the ethanol, simplifying the ethanol production process, and contributing to the self-sufficiency of the farmer. Just the same, the trend toward the use of diesel power on the farm serves to limit a farmer's ability to utilize ethanol in his machinery. Even gasoline engines would require a moderate amount of modification in order to achieve the optimal performance from ethanol.

A fourth choice for the farmer would be not to produce ethanol at all. Or perhaps a cooperative could be formed in order to access the needed capital for a larger scale venture and limiting the risk involved. In view of the time constraints placed on farmers, particularly in the spring and fall seasons, the risk implicated by an additional undertaking may eliminate any likelihood of weighing the possibility of ethanol production. Indeed, as it is described in the following section, ethanol production may appear to be a simple procedure but in order to obtain an acceptable yield, considerable knowledge, care, and time is required of the producer.

2.4.2 Description of an Ethanol Production System

Alcohol, in this case ethanol, production is an age old process. The basic procedure has changed little over the years but new technology has been developed transforming the practice from an art to a science. What follows is a simplified rendition of the process.

The equation depicting the chemical reactions taking place when starch is converted to ethanol is:

$$\underset{\text{(starch)}}{C_6H_{10}O_5} + H_2O \quad \text{(enzyme)} \quad \underset{\text{(sugar)}}{C_6H_{12}O_6} \quad \text{(yeast)} \quad \underset{\text{(ethanol and carbon dioxide)}}{2C_2H_5OH + 2CO_2}$$

This conversion occurs through the physical manipulation of the feedstock as it progresses through a series of distinct mechanical devises. Figure 2-1 exemplifies a typical ethanol production system. Systems differ in the degree of sophistication and automation they incorporate but the underlying operation remains unchanged.

After the feedstock is received it must first be ground to a uniform size to break up the kernal and expose the starch molecules during cooking. Particle size should be such that it allows for the exposure of ample surface area to facilitate hydrolysis and pass freely through the pipes and pumps.

Once the feedstock is ground, it is moved to the cooking tank and mixed with water. A water to feedstock ratio of 3:1 by weight is often recommended. Cooking takes place for one half to one hour at or near boiling to gelatinize the starch. The pH of the slurry at this time should be between 6.0 and 7.0.

After cooking, a fungal analysis culture is added to the cooling mixture to convert the starch to sugar, a process essential to fermentation. Complete hydrolysis of the starch is a function of proper enzymatic action, availability of ample water, particle size and agitation. Additional water may need to be added with the enzyme as the mixture is cooled to 85°-90°F. During this dilution and cooling process most of the starch is converted to simple sugars but sometimes additional time is needed to realize complete conversion. Therefore, it is best to rely on end point analysis rather than trying to follow a rigid time schedule.

Once the mash is cooled, the pH is readjusted to between 4.0 and 4.5 by adding acid. Brewer's yeast and a second enzyme or malt is added with

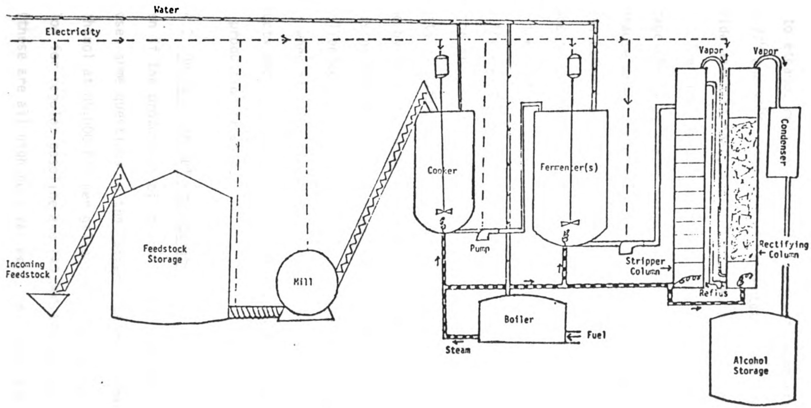

FIGURE 2-1

Simplified Diagram of an Alcohol Production System agitation preparing the beer for fermentation. This conversion of simple sugars to ethanol requires 48 to 72 hours with a maintained temperature between 77^{o} and 90^{o}F. The heat of fermentation is generally sufficient to provide adequate heat, and in fact, may require removal if it becomes too hot. The final product is roughly 10% ethanol, and again, end point percentage should be the criteria signaling the end of fermentation.

Because water and ethanol boil at different temperatures (water at 212^{o}F and ethanol at 173^{o}F) the ethanol in the mixture can be separated and concentrated through distillation. Simply put, the process entails heating the mixture to vaporize the ethanol, collecting the vapors, then cooling the vapors to cause condensation, yielding liquid ethanol. Depending on the process and the still design used, an ethanol at or below 95% purity is obtained from distillation.

The by-product can be separated before distillation by screening and pressing the mash or if the entire mixture is run through the column it is collected after distillation. The final by-product composition depends on when it is collected and is discussed more completely in the by-products section. See Appendix B for a complete description of the ethanol production process.

2.4.3 On Farm Ethanol Utilization

Even if the production of ethanol proves feasible, its utilization still poses some questions to the farmer. Based on heat values, anhydrous ethanol at 85,000 BTU per gallon falls far below the 124,000 BTU per gallon for regular gasoline and 140,000 BTU per gallon for number 2 diesel (these are all high heat values). This indicates that it would take 1.46 to 1.65 gallons of anhydrous ethanol to replace one gallon of gasohol and diesel, respectively.

A comparison of the burning characteristics of the three fuels reveals that ethanol is superior to gasoline as is indicated by its higher octane number, a measure of the fuel's ability to resist detonation during compression.[18/] On the other hand, the cetane number, a measure of the fuel's ignition quality important to compression ignition engines, for ethanol is 3-8. Diesel fuels generally have a cetane rating over 45, the minimum allowable cetane number being 40. Thus, ethanol is not ideally suited for mixing with diesel and cannot be used alone in compression ignited engines.

Moderate adjustments are needed in spark ignition engines and major modifications (i.e., switch over to spark ignition) are required in compression ignition engines before ethanol can be utilized effectively. One such adjustment is, because ethanol is such a good solvent, the replacement of all plastic and rubber engine parts before using it as a fuel (methanol is more corrosive than ethanol). Cold starting can also be a problem when using low proof alcohol. Preheating the fuel prior to injection into the carburetor is suggested by Rider et al., but water condensation in the intake manifold poses an issue demanding more elaborate measures. Here Rider et al. recommend routine, waste heat from the exhaust manifold to head and evaporate the moisture in the intake manifold.[19/]

[18/] Rider, et al., 1979.

[19/] Ibid.

Last but not least, if alcohol is to be used to its fullest potential, it is necessary to increase the compression ratio of the spark ignition engine to 12:1. Conventional spark ignition engines have compression ratios from 6:1 to 8:1. Because of the substantial modifications required to convert a diesel engine to straight alcohol most interest is in using ethanol in diesel engines as a blend requiring anhydrous ethanol or in a dual fueling system. Blends cause a loss of power due to the lower cetane rating of ethanol and dual fueling is an as yet unproven practice.

2.4.4 Utilization of the By-Products

The fermentation of grain produces three products of virtually equal weights; ethanol, carbon dioxide (CO_2), and a concentration of protein and nutrients left behind from the grain. The limited market for CO_2 makes the added expense of collecting and storing it impractical at the farm level. On the other hand the collection and utilization of grain by-product is paramount to the efficient operation of an alcohol enterprise.

The common practice for dealing with the CO_2 produced during fermentation is to allow its release into the atmosphere. Some distillers have captured it for compression into storage containers for resale or use (i.e., in the production of dry ice). The potential here is extremely limited for farm scale operations. Research is being conducted that might develop uses for the CO_2 in prolonging the storage life of the grain portion of the by-products or in greenhouse operations. Until these methods are perfected it will continue to be released.

The removal of the starch from grain leaves behind concentrated fat, fiber, and protein which is a valuable feed for livestock. In essence, the grains are converted from high energy feeds to concentrated protein sources. Commercially, this by-product is separated and dried to three different products, distillers dried grains with solubles (DDGS), distillers dried grains (DDG), or condensed distillers solubles (CDS). On the farm, they will most likely be fed in the wet form as distillers grain and solubles fraction (DGSF), distillers grain fraction (DGF), or distillers soluble fraction (DSF). The nutrient values are the same for both the wet and dry product with only the moisture contents differing.

TABLE 2-4. Nutrient Content of Distillers By-Products

	DDGS or DGSF		DDG or DGF		CDS or DSF	
Moisture, %	8-10	93	8	75	10	97
Crude Protein, %	27		27		28.5	
NE_m, Mcal/lb	.92		.83		.92	
NE_g, Mcal/lb	.61		.61		.61	
Calcium, %	.35		.05		.30	
Phosphorus, %	.95		.37		1.60	
Potassium, %	1.00		.15		2.10	

DDGS has been used in the rations of all farm animals but for monogastrics is limited by its low content of some of the essential amino acids, namely lysine and tryptophan. If synthetic sources for these amino acids are found, as is already the case for lysine, DDGS use for poultry and swine might be more fully exploited. The "unidentified growth factors" on which its use in poultry was based have become less important as nutritional knowledge improved over time. There has also been some DDGS incorporated into pet food products but again this has been on a limited basis.

So far, the greatest potential for expanding the use of DDGS is substitution for soybean meal as a protein supplement. DDGS possesses one particular advantage over soybean meal; it withstands degradation in the rumen better. This refers to the ruminant animal's ability to break down proteins to ammonia and rebuild microbial protein for absorption through its intestinal tract. This advantage is useful only as long as there is sufficient energy available within the rumen to convert the ammonia to microbial protein. If the ammonia utilization potential (AUP) is surpassed, the surplus ammonia is wasted.[20/] Because DDGS defies breakdown as readily as soybean meal, more protein is passed through the rumen with less energy expenditure. The spared energy can then be used to build microbial protein from ammonia provided by a cheaper source such as urea. This advantage exerts itself most profoundly in young growing steers and the lactating dairy cow. It is the nutritionist's task to formulate rations for these animals that maximize production without impairing performance (i.e., conversion of protein does not exceed the animal's ability to convert it to microbial protein) if the advantages of DDGS are to be fully exploited.

Nutritionally, as stated before, the wet and dry by-products are identical, but the high moisture content of the wet by-product presents

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[20/] Waller, et al., 1980.

some unique problems. First of all, when DGSF is used in the rations of high producing animals it must be available daily for extended periods of time. The texture and taste of these rations is very distinct and frequent changes would reduce the animal's consumption causing losses in production.[21/] Furthermore, intake of water by animals is limited leading one to believe that the feeding of DGF with its lower moisture content would be more feasible. Also, straining off the most liquid portion of the by-product would facilitate ease of handling and storage, but deprive the by-product of some of its nutrient value.

Regardless of which by-products are used, storage and handling will still present problems. The storage life of the wet by-product is three to seven days in cool weather and only one to two days in hot weather.[22/] In colder climates, freezing could occur. Insulated storage and rapid consumption once it is fed would be necessities.

2.5 Closure

This chapter was meant to condense and review the existing environment which has served to precipitate and restrict the interest in ethanol production. The approach was general. The following chapters will be more specific in addressing on farm ethanol production.

[21/] David , et al., 1980.

[22/] Adams, 1980.

CHAPTER III

DEVELOPMENT OF THE FARM PLANNING MODEL

3.1 Introduction

The question of whether to add an alcohol production subsystem to a farm is extremely complex because of the many interrelationships within the farming system. Today's commercial family farms are finely tuned technical operations designed to efficiently meet the farm families objectives. Thus, a tool is needed to sort out the intricacies of farms including the impact of an alcohol production unit in the set of farm enterprises. Linear programming was chosen as the tool of analysis because it permits specification of the major subsystems and their interactions from a whole farm perspective, and analysis, within an optimization context. The tool is easy and relatively inexpensive to use.

Use of an LP model makes possible delineation of the major activities and constraints confronting the farm. An LP model depicts the allocation of the farm's land, labor and capital such that profits can be maximized. The impact of entering an alcohol production subsystem into such a model permits determination of demands upon the existing resources and how they should be allocated to the subsystem if it is economically feasible. Equally important, LP lends itself to use in analyzing changes in the "baseline" case. Use of sensitivity analysis enables us to make statements about how the resource allocation would change as pricing and/or input/output relationships are altered.

To bring the decision model into operation, a whole farm is devised that would typify a farming enterprise in the Thumb area of northeastern Michigan. Since the purpose of this study is to determine the conditions necessary to support an alcohol production enterprise, a farm size is chosen which is considered to be large enough to benefit from the economies of scale known to be present in alcohol production. Thus a 750 acre farm with one time capacity to feed 500 to 1000 head of cattle on slated floors is simulated. Three major subsystems are used to represent the farm as depicted by Figure 3-1. Description of the assumptions used in the development of each subsystem follows.

3.2 Structure of the Model

A linear programming model is structured as a series of columns representing possible activities to be included in an objective solution and a number of rows posing boundaries in the form of constraints within which the system must operate. The objective function of the model at hand is profit maximization. This linear optimization model can be viewed in the general mathematical form of:[1/]

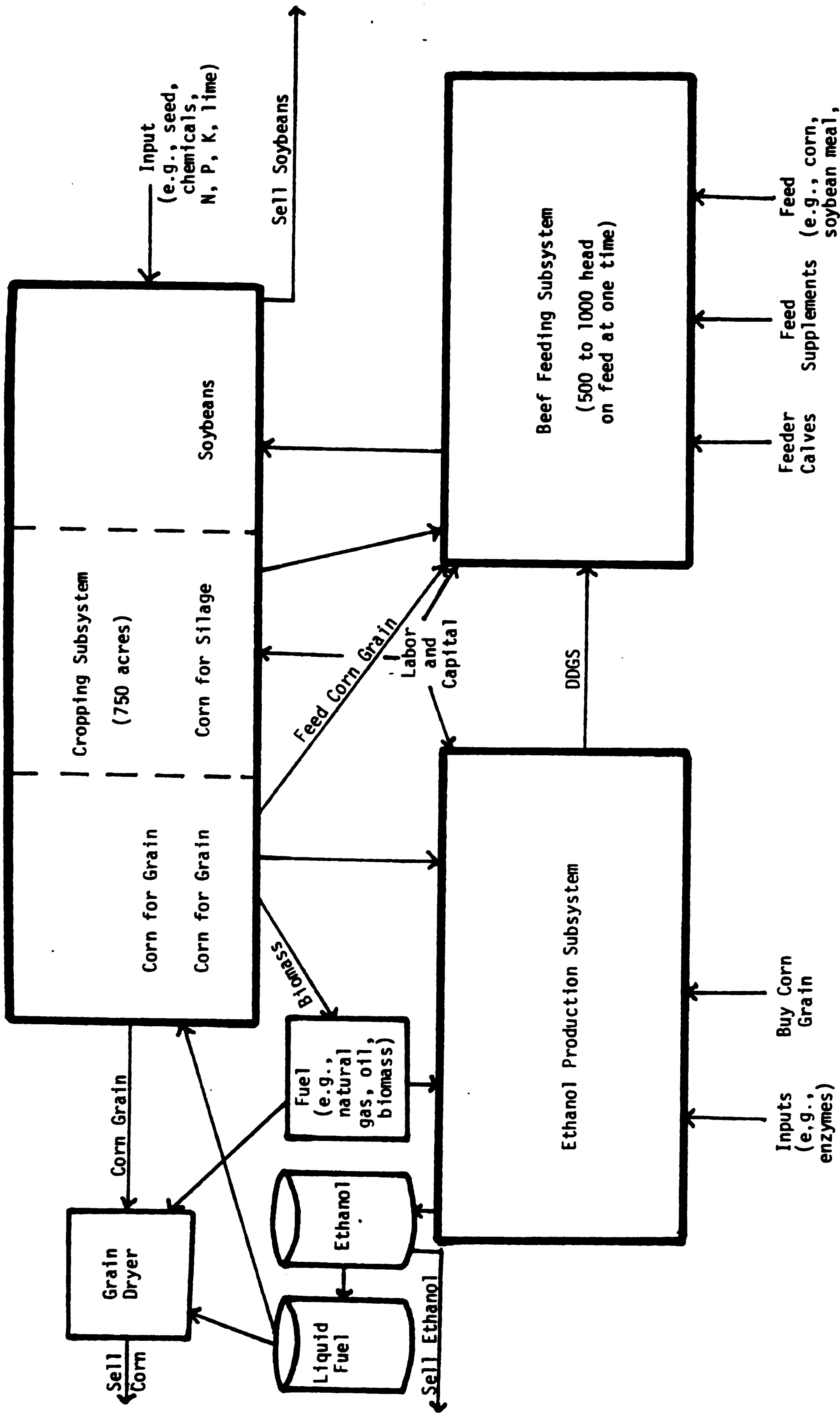
$$\text{Maximize} \sum_{j=1}^{n} c_j x_j$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq, =, \text{ or } \geq b_i \qquad \text{for } i = 1, 2, \ldots, m$$

$$x_j \geq 0 \qquad \text{for } j = 1, 2, \ldots, n$$

[1/] Bradley, Hax, and Magnanti, 1977.



Whole Farm System

FIGURE 3-1

This translates into maximizing profits without exceeding the resource constraints or carrying out any negative activities. C_j is the revenue to be realized by engaging in the j^{th} activity. Total revenue is the product of each C_j and the level at which it occurs, x_j. Further, a_{ij} is the amount of a given resource that the j^{th} activity demands. The sum of all such demands must not exceed the supply of that resource, b_i. Finally, it is not possible to undertake a negative activity; or, in other words, the farmer cannot produce a negative ten acres of corn.

The model is organized in matrix form and is represented in skeleton form in the tableau depicted in Figure 3-2. The matrix has 243 activities and 189 constraints.

3.2.1 Transfer Activities

Transfer activities must be developed to emulate the sequence of activities that take place over time (e.g., plowing must precede fitting which must precede planting). Figure 3-3 depicts the transfer procedures used. The transfer activities are defined on a one acre basis. For example, growing one acre of corn requires the planting of one acre but planting one acre requires plowing one acre. The acre can be plowed in the fall or in the spring, but it must precede planting. Transfer activities demand one acre from the transfer row and supplies it to the next activity's inventory. The right hand side (RHS) for all of these constraints guarantee that the supply (S) of services is always at least as large as the demand for services D; that is $S \geq D$ which implies $S-D \geq 0$ or, alternatively, $-S+D \leq 0$. This insures the preceding activity is completed before the next activity can be undertaken. All of the

Constraints \ Activities	Land Renting (In and Out)	Labor Hiring	Plant and Harvest Corn	Plant and Harvest Silage	Plant and Harvest Soybeans	Field Activities	Transfer Activities	Buy Inputs	Sell Outputs	Buy Liquid Fuel	Buy Btu's	Buy Cattle	Feed Cattle	Sell Cattle	Buy Feed	Buy Feedlot Space	Buy theanol Pro-duction Unit	Produce Ethanol	Sell Ethanol and DDGS
Land Constraints	X		X	X	X														
Labor Constraints		X	X	X	X	X													
Weather Constraints			X	X	X	X													
Inventory of Field Activities						X	X				X								
Transfer Rows		X	X	X	X	X	X												
Crop Input Balance			X	X	X	X		X											
Crop Production Balance			X	X	X				X						X				
Liquid Fuel Balance			X	X	X	X				X								X	
Btu Balance											X							X	
Cattle Balance												X	X	X					
Feedlot Constraint													X			X			
Feed Balance													X		X				
Ethanol Production Capacity																	X	X	
DDGS Balance															X			X	X
Ethanol Balance																		X	X

Skeleton Representation of the Whole Farm Tableau

FIGURE 3-2

Constraints \ Activities	Plow S_1	Plow S_2	Transfer Plow S_1 to SBP S_1	Transfer Plow S_1 to SBP S_2	Transfer Plow S_1 to SBP S_3	Transfer Plow S_2 to SBP S_2	Transfer Plow S_2 to SBP S_3	SBP S_1	SBP S_2	SBP S_3	Transfer SBP S_1 to Plant S_1	Transfer SBP S_1 to Plant S_2	Transfer SBP S_1 to Plant S_3	Transfer SBP S_2 to Plant S_2	Transfer SBP S_2 to Plant S_3	Transfer SBP S_3 to Plant S_3	Plant S_1	Plant S_2	Plant S_3		RHS
Plow S_1 Inventory	1																				≤ 0
Plow S_2 Inventory		1																			≤ 0
Plow S_1 to SBP Trans.	-1		1	1	1																≤ 0
Plow S_2 to SBP Trans.		-1				1	1														≤ 0
SBP S_1 Inventory			-1					1													≤ 0
SBP S_2 Inventory				-1		-1			1												≤ 0
SBP S_3 Inventory					-1		-1			1											≤ 0
SBP S_1 to Plant Transfer								-1			1	1	1								≤ 0
SBP S_2 to Plant Transfer									-1					1	1						≤ 0
SBP S_3 to Plant Transfer										-1						1					≤ 0
Plant S_1											-1						1				≤ 0
Plant S_2												-1		-1				1			≤ 0
Plant S_3													-1		-1	-1			1		≤ 0

Mechanism for Transferring Cropping Activities Between Each Other and Between Periods (S_i refers to the ith Period in the Spring Season

FIGURE 3.3

cropping activities are linked in this manner to form a loop representative of a continuous operation.

3.3 The Cropping Subsystem

The cropping activities are set, exogenously, to have 150 acres of soybeans and six hundred acres of corn. Corn acreage can be any combination of grain and silage. If harvested as corn grain it can either be dried and sold or stored as high moisture corn for use in the beef and/or alcohol subsystems. Corn silage is stored and fed to cattle. All of the soybeans are sold at harvest. The activities in the model are selected as being the most feasible as indicated by James Lehramann.[2/] Yield is affected by planting and harvesting dates as well as plant variety. The 115 day corn variety appeared to be the most attractive while soybeans included 117 day, 123 day, and 128 day varieties. Corn silage yields are based on 16 ton/acre corn adjusted for length of growing periods. Tables 3-1, 3-2, and 3-3 illustrate the activities available to be included in the solution set as the cropping subsystem.

3.3.1 Fertilizer Requirements

The amount of nutrients (N, P, and K) removed from the soil by different crops varies considerably. As a result, the fertilizer requirements for each crop differs. The method of harvest further affects nutrient removal. If corn is harvested as silage, nitrogen and potassium are removed in larger amounts because the organic material found in the leaves and stalks is not left in the field as in corn grain harvesting.

[2/] Lehramann, 1976.

TABLE 3-1. Corn[a] Yield (bu/acre) and Moisture Content as a Function of Planting and Harvesting Dates

Planting/ Harvesting	April 20 to April 29 (S_1)	April 30 to May 9 (S_2)	May 10 to May 19 (S_3)
Oct. 1 to Oct. 15 (F_3)	100[b] (30)[c] 110 bu[d]		
Oct. 16 to Oct. 30 (F_4)	98 (26) 107.8 bu	97 (28) 106.7 bu	90 (32) 99 bu
Oct. 31 to Nov. 15 (F_5)	93 (22) 102.3 bu	93 (24) 102.3 bu	85 (26) 93.5 bu

[a] 115 day corn.

[b] % yield; 100% = 110 bu/acre.

[c] % moisture.

[d] bu/acre.

TABLE 3-2. Soybean Yield (bu/acre) as a Function of Variety and Planting and Harvesting Dates

Planting/ Harvesting	May 10 to May 19 (S_3)	May 20 to May 29 (S_4)	May 30 to June 9 (S_5)
Sept. 15 to Sept. 30 (F_2)	38.8[a/] 123 day	38.0 117 day	
Oct. 1 to Oct. 15 (F_3)	35.95 128 day	35.95 128 day	
Oct. 16 to Oct. 30 (F_4)			25.80 128 day

TABLE 3-3. Corn Silage Yield (ton/acre) as a Function of Planting and Harvesting Dates

Planting/ Harvesting	April 20 to April 29 (S_1)	April 30 to May 9 (S_2)	May 10 to May 19 (S_3)
Aug. 31 to Sept. 14 (F_1)	16.5 ton	16 ton	15.5 ton
Sept. 15 to Sept. 30 (F_2)	17 ton	16.5 ton	16 ton

When biomass is used after corn grain harvest, the effect on the soil is analogous to silage removal. It is generally considered that legumes, unless the soil is unusually poor, will get an adequate supply of nitrogen from the air. Soybeans, being a legume, require no nitrogen. Table 3-4 lists the fertilizer requirements used in the model.

TABLE 3-4. Fertilizer Requirements, lbs/acre

	Feed Grain[a]	Corn Silage (16 ton/acre)[b]	Soybeans[a]
Nitrogen (N)	137.5	150.4	
Phosphorus (P_2O_5)	52.25	57.6	33.0
Potassium (K_2O)	37.2	124.8	54.6

[a] Hoskin, 1979.

[b] Vitosh, 1979.

3.3.2 Variable Costs

Variable costs were budgeted as the cost of conducting a given cropping activity on one acre. These costs include herbicides, an insecticide on the corn acreage since the rotation is continuous, limestone, grease and oil and marketing cost when the crop is sold. Also, interest on working capital of 14 percent for six months is charged. The variable costs for each of the cropping activities are shown in Tables 3-5, 3-6, and 3-7.

TABLE 3-5. Variable Costs for Corn and Corn Silage

Item	Requirement, Units/Acre		Cost/ Unit	Cost/ Acre
Herbicide				
Artrazine	.5	lbs active ingredient	2.27	1.135
Sutan	3.3	lbs active ingredient	2.28	7.524
Lasso	2.0	lbs active ingredient	3.49	6.98
Insecticide				
Furadan	.75	lbs active ingredient	6.31	4.73
Limestone	3	tons every 5 years	10.00	6.00
Grease and oil	15%	of fuel usage	corn	1.36
			corn silage	1.98
Subtotal			corn	27.729
			corn silage	28.349
Interest on working capital for six months @ 14%			corn	1.941
			corn silage	2.08
Total Cost			corn	29.67
			corn silage	30.43

TABLE 3-6. Marketing Cost* and Total Variable Cost for Dry Corn

Planting/Harvesting Duration	Dry Yield bu/acre	Marketing Cost	Total Cost
S_1F_3	110	11.00	40.67
S_1F_4	107.8	10.78	40.45
S_1F_5	102.3	10.23	39.90
S_2F_4	106.7	10.67	40.34
S_2F_5	102.3	10.23	39.90
S_3F_4	99	9.90	39.57
S_3F_5	93.5	9.35	39.02

*If corn grain is to be marketed there is a $.10 per dry bushel charge to cover transportation and marketing expenses.

TABLE 3-7. Variable Cost for Soybeans

Item	Requirement, Units/Acre	Cost/ Unit	Cost/ Acre
Herbicides			
Lasso	2 lb active ingredient	3.49	6.98
Larox	.75 lb active ingredient	7.14	5.355
Limestone	3 ton every 5 years	10.00	6.00
Grease and oil	15% of fuel usage		1.248
Interest on working capital for six months @ 14%			1.37 20.953
Marketing Cost	.10/bu		
	PS_3 HF_2 123 day		3.80
	PS_3 HF_3 128 day		3.60
	PS_4 HF_2 117 day		3.80
	PS_4 HF_3 128 day		3.60
	PS_5 HF_4 128 day		2.58
Total Cost			
	PS_3 HF_2 123 day		24.75
	PS_3 HF_3 128 day		24.55
	PS_4 HF_2 117 day		24.75
	PS_4 HF_3 128 day		24.55
	PS_5 HF_4 128 day		23.53

3.3.3 The Machinery Complement

The machinery complement is entered as a fixed component of the farm. In order to do this, an adequate machinery complement had to be generated outside the model which would provide, with reasonable certainty, that the field operations would be completed each year. The most important factors affecting the completion of field work are: (1) the amount of land to be cultivated; (2) the labor availability and wage rates; and (3) weather patterns. The first two are known with near certainty; weather can only be described in probabilistic terms.

A machinery selection computer model developed by Fran Wolak, of the MSU Agricultural Engineering Department, was used to develop a machinery complement that could complete all operations within the allotted time period 57 years out of 100. After the selection of a tillage system, moldboard plow, the next step was to identify the operations and the time period within which they are to be accomplished. As listed in Tables 3-8 and 3-9, one can see that the date constraints differ slightly between those used in the Wolak model for deciding the machinery complement and those used in the whole farm LP model. This difference is a result of modifying the spring and summer time periods in order to accommodate a richer view of farming practices in the Michigan Thumb area. The LP model's constraints are adapted from previous work done by Lehrmann (1976). At any rate, the divergence is small and in most cases the time constraint is relaxed slightly in the whole farm LP model thereby increasing the probability that the machinery complement generated by the Wolak model could complete the operations within the time constraints of the whole farm LP.

TABLE 3-8. Operations for Corn and Corn Silage

Operation	The Wolak Model		The Whole Farm LP	
	Starting Date	Ending Date	Starting Date	Ending Date
Silage Harvest	828	925	831	930
Grain Harvest	1009	1113	1001	1115
Fertilizer Spreader	1009	1127	1016	1201
Disking	1009	1127	1016	1201
Moldboard Plow	1009	515	1016	519
Field Cultivation	424	515	420	519
Planter	424	515	420	519
Sprayer	424	515	420	519
NH_3	529	619	530	620
Row Cultivation	529	619	530	620

TABLE 3-9. Operations for Soybeans

Operation	The Wolak Model		The Whole Farm LP	
	Starting Date	Ending Date	Starting Date	Ending Date
Harvest	925	1023	915	1015
Fertilizer	1009	1127	1016	1201
Moldboard Plow	1009	605	1016	609
Disk Harrow	410	605	420	609
Field Cultivator	515	605	420	609
Planter	515	605	510	609
Sprayer	515	605	510	609
Row Cultivator	619	703	610	701

The size of the farm is set at 750 acres of which 150 acres is reserved for soybeans and the remaining 600 acres varies between corn and corn silage. The machinery complement is able to accommodate all corn, all silage or a combination of the two. The Wolak model lacked a silage harvesting component; this component was hand budgeted. All operations other then harvesting, are the same for corn grain and corn silage.

A two man labor force operates the machinery complement. The Wolak model was run with different amounts of labor availability before it was decided to use a two man operation. The annual use cost of machinery to move from a two man complement to a one man complement is $22,000 per year. An additional man can be hired year round for this amount (or less) and he would be available for additional chores other than field work. A three man operation was not considered since farms of this size are seldom, if ever, operated by more than two owners and it was not desirable to assume hired labor.

The resulting machinery complement is shown in Table 3-10. The annual use costs per acre were $71.26, $71.00 and $77.00 for all the corn, corn-corn silage mix, and all silage systems, respectively.

Fuel cost was included in the total charge per acre for the machinery complement, but because fuel use is to be examined separately it had to be subtracted out. The fuel consumption reported below in Table 3-11 includes all activities in the model but does not include hauling the harvested product from the field to storage. These differ with each activity, depending on yield and are reported in Appendix A. Table 3-12 lists the net cost for each cropping sequence.

TABLE 3-10. Machinery Complement

Implement	Size	Field Eff.	Field Crop (hr/acre)	Fuel Cons. (gal/acre)
Tillage tractor	150 hp			
Utility tractor	150 hp			
Machinery for harvest				
All corn				
combine	8 row			
corn head	8 row	.70	.212	1.60
grain head	16 feet	.70	.268	1.10
Corn-corn-silage				
combine	4 row			
corn head	4 row	.70	.424	1.60
grain head	13 feet	.70	.330	1.10
silage chopper	3 row	.70	.735	2.67
All silage				
combine	4 row			
corn head	4 row	.70	.424	1.60
grain head	10 feet	.70	.397	1.10
silage chopper	2-3 row	.70	.735	2.67
Implements Constant for All Combinations				
Fertilizer spreader	60 feet	.70	.042	.19
Moldboard plow	6 bottom	.80	.342	3.14
Field cultivator	25.5 feet	.70	.078	.73
Planter	12 row	.55	.102	.70
Sprayer	30 feet	.65	.085	.25
NH_3 applicator	8 row	.65	.134	.62
Row cultivator	8 row	.80	.03	.47
Disk	25.58 feet	.85	.089	.73
Disk Harrow	21.5 feet	.80	.116	1.02

TABLE 3-11. Fuel Cost for Machinery Complement

Crop	Fuel Consumption (gal/acre)	Cost ($.75/gal)
Soybeans	8.14	$6.105
Corn	8.43	6.323
Corn Silage	10.23	7.673

TABLE 3-12. Net Cost for Machinery Complement

Crop	Total Cost	Fuel Cost	Net Cost
All Corn	$71.26	6.279	64.981
Corn-Corn Silage	71.00	6.819	64.181
All Silage	77.00	7.359	69.641

3.3.4 Field Activity Coefficients

Some of the field activities are combined to simplify the model. This is done only where the activities are carried out in the same periods and where corn and soybeans differed in the activities needed to grow each. For instance, land planted to soybeans does not require the application of ammonia while corn acreage does. Both need to be cultivated after the seedlings have emerged. So, the ammonia application and row cultivation are combined for corn. Furthermore, it is evident by the examination of the computer print out depicting the timing and sequence of the activities used in determining the machinery complement, that spraying of herbicides takes place in the same week as does planting. Thus, these two activities are combined. Modern technology has made it possible to actually pull both sprayer and planter with a single tractor but the time needed is recorded here as if they are carried out separately.

The activity described as seedbed preparation consists of field cultivation for land to be planted in corn and soybeans and disk harrowing for land to be planted only in soybeans. To avoid the complications involved in transferring land into separate planting activities, the seedbed preparation activity is defined as requiring all of time needed to field cultivate the entire acreage plus the time required to disk harrow 20 percent of the land, since this is the limited area for soybeans. The compromise is for a slight loss of reality in the model in return for a substantial gain in simplified mechanics, not to mention a reduction in the size of matrix.

A separation of activities can not be avoided in the fall after harvest when only corn grain land required disking. All land is to be fertilized in the fall so a fertilizer and disk activity is defined for the corn grain land. The corn silage and soybean land is transferred into a fertilize only activity. After these separate activities are carried out, all land is transferred into the same plow activity. The rest of the model follows conventional transfer procedures. Table 3-13 indicates the field operations and their time requirements both in terms of field time and labor requirements. The labor time for field activities is calculated as being ten percent greater then the tractor time requirements. This is an assumption made in order to more realistically depict the amount of time used to prepare and maintenance machinery, fill planters, travel to fields, etc.

3.3.5 Weather Constraints

The total hours available are assumed to be 18 hours per day in the spring periods (this allows for 25 percent down time per working day) and 10 hour days in the fall periods. The fall periods are only 10 hours because harvesting is limited in the first four periods by the moisture in the field or toughness of the plants. The later fall periods are also considered to have 10 hour days due to the coldness, shorter days and unwillingness on the part of the farmer to be in the field any longer then this. The weather constraints are listed in Table 3-14.

The first five periods in the spring have a tractor constraint equal to twice the weather constraint. In these periods, there are more field activities then there are tractors to perform them simultaneously making

TABLE 3-13. Coefficients for Time Requirements of Field Operations

	Field Time Required (hr/acre)	Labor Time Required (hr/acre)
Harvest		
Corn silage	.735	1.618[c]
Soybeans	.268 (.330)(.397)[a]	.59 (.726)(.874)
Corn grain	.212 (424)[b]	.466 (.932)
Fertilize	.042	.046
Fertilize and disk	.131	.144
Moldboard plow	.342	.376
Seedbed prep.	.101	.111
Planting and spray	.187	.206
Row cultivate	.03	.033
Row cult. and NH_3	.164	.180

[a] The first number in parenthesis is the time required for the 13' grain head of the corn-corn silage machinery complement. The second number is the time required of the 10' grain head of the all silage complement.

[b] The number in parethesis is the time required of the small corn head of both the corn-corn silage mix and all silage complements.

[c] The labor requirements for all of the harvest activities is doubled since both operators are required to carry out the harvesting and hauling activities.

TABLE 3-14. Weather Constraints

Period	Days in Period	% Good[a/] Days	Total Hours Avail.	Tractor Constraints
S_1	10	44	79.2	158.4
S_2	10	50	90	180
S_3	10	41.1	73.98	147.96
S_4	10	66.5	119.7	239.4
S_5	11	70	138.6	277.2
S_6	11	70	138.6	
S_7	11	70	138.6	
F_1	15	70	105	
F_2	16	65.9	105.44	
F_3	15	53	79.5	
F_4	15	35.7	53.55	
F_5	16	23.5	37.6	
F_6	16	14	22.4	

[a/] The percentage of days listed as suitable for field work was taken from TELPLAN 18 data for drained sandy loam soils.

tractor availability the constraining factor. Weather alone is the limiting constraint in all other periods.

3.3.6 Family Labor Availability

The labor constraints for each period are calculated in a way that reflects the hours available to carry out the activities in the model. These hours are to be supplied only by the family. The family is defined as having the equivalent of 1.34 full time operators. This is reported as the average for 600 acre farms in the Saginaw Valley.[3/] In order to depict the farmer's desire to take weekends and holidays off in the slack months and to work between six and six and a half days a week during seasons when timing is critical, the total days in each period is adjusted and reported as the days willing to work. Another adjustment is made to the hours the farmer works each day, and for the lack of a better heading, called the hours of actual work. This is done under the assumption that a considerable part of each day is spent taking care of unexpected business, eating, and managing the farm. As farm enterprises increase, farm management takes an ever increasing amount of time. In this model we are interested only in the time available to carry out the activities in the model. Accordingly, the efficiency for carrying out only these activities ranges from 75% for a fourteen hour day to 87.5% for an eight hour day. So, even though a farmer puts in a fourteen hour day only 10.5 hours are available for the activities in the model.

[3/] Kelsey and Johnson, 1979.

A particular problem arose when considering how to prevent family labor from being used exclusively for the field activities when in fact weather and tractor constraints prevent this from being the case. As a result, it is necessary to have two sets of constraints for family labor; one represents the time available for field work and the other is allocated to tending cattle, producing alcohol, or sold. The labor selling activities are used as a means of placing a reservation price on the farmers labor (i.e., labor sold at a price of $1.50 per hour would indicate that the farmer would rather not work at all unless his labor returns at least $1.50 per hour). Excess family labor for field time is transferred to the family labor for other activities via labor transfer activities. This arrangement insured that family labor is used before any labor is hired (as long as the farmers labor reservation price was below the hired labor cost) but in periods when weather constrains the time the farmer can be in the field and it is desirable to accomplish as much as possible during this time, hired labor has to be used when the number of activities are greater then the number of laborers provided by the family. In other words, it prevents the farmer from being in two places at once. The family labor for field work is determined with consideration for weather and tractor usage, and is reported in Table 3-15.

Although these hours are available to carry out any of the activities, the critical nature of the timing of the cropping activities provides the impetus for the farmer to prolong his work day. Therefore, it is fitting to include family labor availability in the cropping subsystem section.

TABLE 3-15. Family Labor Availability

Period	Days/ Period	Days Willing to Work	Hrs. of Actual Work	Hours/ Period	X1.34
Dec. 2-Apr. 19	139	100	7	700	938
S_1	10	8	9	72	96.48
S_2	10	8.5	9	76.5	102.51
S_3	10	9	10.5	94.5	126.63
S_4	10	9	10.5	94.5	126.63
S_5	11	9.5	10.5	99.75	133.665
S_6	11	9	9	81	108.54
S_7	11	9	9	81	108.54
July 2-Aug. 30	60	43	8	344	460.96
F_1	15	13	9	117	156.78
F_2	16	14	10.5	147	196.98
F_3	15	13.5	10.5	141.75	189.945
F_4	15	13.5	10.5	141.75	189.945
F_5	16	14	8	112	150.08
F_6	16	14	8	112	150.08
	365	287			

3.3.7 Storage and Drying

The storage of high moisture corn and corn silage is provided for in the model by activities which allow the farmer to buy storage capacity. In this way, no more storage capacity then is necessary is used. This is not entirely the case in reality, but the model is useful in aiding the farmer in deciding upon the storage capacity he should have.

An activity to buy drying capacity is included. The reasoning behind its inclusion is not so much to assist in the process of buying a dryer as it is to provide a means of examining rising drying cost.

Also, by having this separate activity, the model will be able to transfer in alternative fuel sources, such as biomass or alcohol.

All other activities associated with the cropping subsystem are input buying or output selling activities, not to mention the numerous transfer activities needed to move from one cropping procedure to the next between and within time periods.

3.4 The Beef Subsystem

The beef production subsystem is assumed to have a "one time capacity" of 500 to 1000 head in a slated floor barn. The representative animal is an average frame and conditioned steer calf receiving a growth stimulant such as Ralgro. The steer is purchased at 450 pounds and sold as a yield grade 3, choice grade at 1050 pounds. A variety of rations were formulated and used as the basis for determining total feed disappearance for the year.

3.4.1 Balancing the Rations

A modified version of TELPLAN 44[4/] was used to obtain balanced rations (feed budgets) for use in the LP model. The modifications were necessary in order to take advantage of the "protected protein" properties of DDGS.[5/] The following constraint was added to insure that ammonia utilization potential (AUP) of the rumen was not surpassed:

$$CP \times d_j \times 454 \times .85 \leq TDNUB \times 2$$

where:

- CP = crude protein of the feed (lb/lb feedstuff)
- d_j = the degradation rate of the feed ($1 \geq d_j \geq 0$)
- TDN = total digestible nutrients (lbs)
- UB = upper bound on rumen NH_3 (lbs crude protein equivalent/kcal digestible energy)
- .85 = net fraction of NH_3 retained in the rumen
- 454 = converts pounds to grams
- 2 = a constant (converts lbs TDN to kcal digestible energy)

Thus designed the model makes the most efficient use of the feeds' capacity to by-pass undegraded protein while remaining within the animal's capacity to convert ammonia to microbial protein.

The rations utilize three protein sources (soybean meal, DDGS and urea) and two energy sources (corn grain and corn silage). Limestone and dicalcium phosphate are included to meet the animal's calcium and phosphorus requirements. The nutrient composition of the ration ingredients are depicted in Table 3-16.

[4/] Fox and Black, 1977a, 1977b.

[5/] Black, Waller and Jackson, 1982.

TABLE 3-16. Nutrient Composition of Ration Ingredients[a]

Item	Corn Grain	Corn Silage	DDGS	SBM	Urea
	Dry Matter Basis				
NE_m Mcal/lb	1.02	.71	.92	.88	0
NE_g Mcal/lb	.67	.45	.61	.57	0
TDN, %	91	70	82	81	0
Crude Protein, %	10.0	8.0	27	50	281
Net Protein, %	3.5	1.6	9.4	17.5	98
Protein degraded in the rumen, % of crude protein	56	50	62	72	100
Dry matter, %	72	32	7	90	100

[a] Waller, et al., 1980.

These feeds are used in various combinations to develop four rations: (1) "1%" or .53 Mcal NE_g/1g ration; (2) two-phase ration; (3) .63 Mcal NE_g/lb ration; and (4) .44 Mcal NE_g/lb ration. Corn is fed a rate of one pound per hundred pounds of body weight per head per day for the 1% ration. In the two-phase system a low energy diet (.44 Mcal NE_g/lb) is fed from 450 pounds to 800 pounds and a high energy diet (.65 Mcal NE_g/lb) is fed during the finishing phase of 800 to 1050 lbs. Each feedstuff is reported as a percent of the dry matter intake.

3.4.2 Determining the Feed Disappearance

To initiate the process of determining feed disappearance, feeding periods were chosen and the number of days in each period was calculated. The periods are defined as:

period 1 - 450 to 600 lbs

period 2 - 600 to 800 lbs

period 3 - 800 to 1050 lbs

For period one and two, daily weight gain for a given ration are constant; in period three, daily gain decreases and dry matter intake increases because daily dry matter intake per unit of metabolic weight (weight 3/4) increases as the body weight went from 800 lbs to 1050 lbs.[6/] Also, a two week adjustment period is added to the first period and it is assumed that dry matter intake is 90 percent of normal and that the time is required to regain tissue losses due to time in transit from the cow calf operator to the feedlot. This is the generally accepted length of time

[6/] Fox and Black, 1977, 1982.

needed to bring the calves on feed and allow them to adjust to the new environment. Accordingly, the days in period one are the total weight gained in the period divided by the daily gain plus two weeks. The days in period two are calculated by dividing the total weight gained by the daily gain. In period three, the days are figured at fifty pound intervals since the daily gain is changing. Table 3-17 lists the number of days required to feed an animal from 450 pounds to 1050 pounds. A .5 percent tissue shrinkage during marketing is assumed so the animal is actually fed to 1055 pounds. A weighted average over each period is used as the average consumption per day per period. Table 3-18 has the average daily consumption in pounds of dry matter for each ration during the three periods.

The head per year is 330 divided by the total days needed to feed the animal from 450 lbs to market weight. A year 330 days total is chosen to take account of operation below capacity during turn over and maintenance. This figure assumes a 90 percent of capacity level of operation.

The total feed disappearance per period in pounds of dry matter is the days in each period times the average consumption per day and are given in Table 3-19. Final calculations for the total feed disappearance are total dry matter disappearance per period times the level that each feed enters the ration. Table 3-20 shows the results of those calculations.

3.4.3 Time Used for Handling Feed and Manure

The time required to handle feed increases as the percentages of dry matter in the ration decreases because the farmer is moving a larger amount of bulk for the same nutrient value. Accordingly, rations that

TABLE 3-17. Days Required to Feed Animal from 450 to 1050 Pounds

Period	.44	.53	NE_g, Mcal/lb .63	Two Phase
1	96.192	76.448	69.567	96.192
2	109.589	83.264	74.101	109.589
3	156.592	117.08	103.477	156.592
Total	362.373	276.792	247.154	309.258

TABLE 3-18. Average Daily Dry Matter Consumption, Pounds

Period	44 Mcal/lb	53 Mcal/lb	63 Mcal/lb	Two Phase
1	12.98	12.88	11.64	12.98
2	16.58	16.58	15.04	16.58
3	14.48	19.48	17.67	17.67
Turnover rate, Hd/year	.91	1.19	1.34	1.07

TABLE 3-19. Total Dry Matter Disappearance, lbs per Period

Period	44 Mcal	53 Mcal	63 Mcal
1	1248.09	984.344	809.93
2	1816.76	1380.351	1114.70
3	3049.63	2279.665	1828.13

TABLE 3-20. Feed Disappearance, (Pounds of Dry Matter per Year)

	Feedstuff						
Ration	Corn	Soybean Meal	DDGS	Urea	Corn Silage	Lime-stone	Dicalcium Phosphate
1% 53 Mcal NE_g/lb							
Soybean + Urea	2101	77		32	3293	12	22
Soybean - Urea	1909	304			3293	12	22
DDGS + Urea	2050		133	35	3507	12	21
DDGS - Urea	1552		702		3261	14	11
Two Phase							
Soybean + Urea	1631	20		33	3507	12	19
Soybean - Urea	1631	323			3347	12	16
DDGS + Urea	1631		26	33	3501	12	24
DDGS - Urea	1631		435		3134	12	9
.44 Mcal NE_g/lb							
Soybean + Urea		33		56	5459		22
Soybean - Urea		368			5186		17
DDGS + Urea			45	56	5448		22
DDGS - Urea			741		4824		6
.63 Mcal NE_g/lb							
Soybean + Urea	4266			29	660	30	23
Soybean - Urea	4096	199			633	30	21
DDGS + Urea	4266			29	660	30	23
DDGS - Urea	3864		457.39		641	34	15

include DDGS at 7 percent dry matter are going to be more difficult to feed than a ration that uses soybean meal at 90% dry matter. The total wet weight of each ration is determined by dividing the dry matter requirements by the percent dry matter for each feed and summing the quotients. The resultant number is then multiplied by the time required per pound (.0001) to arrive at a total time requirement per year for feeding each ration.[7/] The yearly requirements, based on a 330 day "animal year" are spread evenly over the entire year. The results range from 2.6 hours per year per animal for the low energy (.44 Mcal NE_g/lb) ration with DDGS as a protein source to .8 hours per year per animal for the high energy (.63 Mcal NE_g/lb) ration with soybean meal as a protein source.

The ration energy concentration affects the quantity of manure an animal will excrete and the quantity of manure, in turn, has an influence on its handling time. As the percent grain in the ration dry matter decreases, the total volume of manure produced increases because of the lower digestibility of roughages. As in feed handling, this fact favors the high energy rations by a lower nonfeed cost per animal fed. Labor requirements for manure handling are (in hours per head capacity per year) .429, .579 and .679 for the .44 Mcal NE_g/lb 1% and two-phase and 63 Mcal NE_g/lb rations, respectively. These requirements are distributed equally over the whole year.

[7/] Woody and Black, 1978.

3.4.4 Manure Credit as a Fertilizer Source

The grain content of the ration dry matter has an additional effect on nonfeed costs since it influences the concentration of nutrients in the manure. The nutrients available from manure are depicted in Table 3-21.

3.4.5 Fixed and Variable Costs for Beef Subsystem

The fixed and variable cost for the beef subsystem are developed using unpublished data of John Waller of the Animal Science Department at Michigan State University. The cattle are assumed to be fed in a slated floor barn with an area of sixteen square feet allowed per animal. The feedlot and supporting equipment are treated as a fixed cost to be paid for irregardless of how many cattle are on hand. This charge is calculated on a per head basis for investment decisions, since they should be relatively independent of scale over the 700 to 1000 head size range.

Variable costs include growth stimulants, death loss, transportation, veterinary, and marketing charges. All variable costs are on a per head basis, and differed with the ration being fed since this affected the number of steers fed each year. Total variable costs are presented in Table 3-22; Appendix A itemizes the charges.

3.5 The Alcohol Subsystem

To arrive at a typical farm scale alcohol production unit is a precarious endeavor. There abound a multitude of conflicting claims and reports as to what particular fermenting and distillation equipment can and cannot do; the practice employed here is to use the information from well documented and reputable sources when a consensus exists. When this

TABLE 3-21. Nutrients Available from Manure[a/]

Item	.44 Mcal NE_g/lb (40% Grain)	1% & 2 Phase (60% Grain)	.63 Mcal NE_g/lb (90% Grain)
Lb/head/day			
Nitrogen (N)	.13	.13	.11
Phosphorus (P_2O_5)	.10	.08	.07
Potassium (K_2O)	.10	.09	.07
Lb/head/year (330 days)			
Nitrogen	42.9	42.9	36.3
Phosphorus	33.0	26.4	23.1
Potassium	33.0	29.7	23.1

[a/]Percent of nutrients available to corn plants: N 55%; P_2O_5 75; K_2O 90%.

TABLE 3-22. Variable Cost for Feeding Steers the Various Rations

Ration	Variable Cost
.44 Mcal NE_g/lb	$ 94.96
1% Ration	85.45
Two Phase	73.58
.63 Mcal NE_g/lb	105.91

is not possible, the available information is used to arrive at a point from which to begin the analysis. These "unknowns" will be subjected to a sensitivity analysis in order to establish their impact on the economic efficacy of alcohol production.

The process of establishing an alcohol subsystem began by choosing the yearly capacities of the stills. One analysis will be made for a still whose yearly output of DDGS just matches the requirement of the beef subsystem. As a reference point for the amount of DDGS that could be utilized by the cattle, the 1% ration was used. In the initial analysis, sale of DDGS is prohibited because use of the wet by-product is assumed and it is not considered transferable except for very short distances. If the feedlot's capacity were fed the 1% ration year round, 701,980 pounds of DDGS on a dry matter basis would be used. A 100,000 gallon still would provide 700,000 pounds of dry DDGS. This was chosen to be the size of one of the "reference" stills. It is assumed that a market and infrastructure exist for the marketing of the surplus alcohol.

A second size "reference" still would just provide the farm with enough fuel to carry out all of its normal farming activities; a 12,500 gallon per year still would be adequate. Of course this assumes that all the needed modifications have been made to the farm machinery. If one wishes to drop this assumption, the yearly cash flow used to support the alcohol subsystem would have to be used to retrofit the machinery as well.

Even though most farm operated stills were achieving less then a two gallon per bushel conversion, the more optimistic ratio of 2.5 gallons per bushel of corn was used here since these conversion rates have been achieved at the MSU farm scale facility.[8/] This conversion ratio can and must be realized through proper end point quality control before alcohol production can be economized.

Since the corn to be used in the still is being transferred in pounds of dry matter, it is necessary to convert the stills demand for corn into dry matter. A bushel of No. 2 corn (84.5% moisture) would be 47.32 pounds of dry matter. The production of DDGS will be 17.5 pounds of dry matter per bushel of corn.

The BTU requirements for the cooking and distillation processes were taken from two studies conducted by the Indianapolis Center for Advance Research (ICFAR) and ACR Process.[9/] For cooking, the ICFAR reported that 45.8 pounds of steam are needed per bushel of corn. ARC process reports that 180 pounds of steam are required to distill a bushel of corn. This combined steam requirement of 225.8 pounds can be converted to boiler horse power (1 BHP = 34.5 lbs of steam per hour at 1.0 boiler efficiency) and then to BTU (1 BHP = 33480 BTU per hour at 1.0 boiler efficiency).

$$225.8 \text{ lbs steam/bu corn} \times \frac{1 \text{ bu corn}}{2.5 \text{ gallon}} = 90.32 \text{ lbs/gal}$$

$$90.32 \text{ lbs of steam/gal of ethanol} \times \frac{\text{BHP-hour}}{34.5 \text{ lbs of steam}} = 2.62 \text{ BHP hour/gal}$$

$$2.62 \text{ BHP-hour/gal of ethanol} \times \frac{33480 \text{ BTU}}{\text{BHP-hour}} = 87{,}649.67 \text{ BTU/gal}$$

Older broilers are reported as having an efficiency of 0.6; the ARC process uses a broiler efficiency of .8. To be prudent, and at the same time reflect the trend toward more efficient broilers, a broiler

8/ Waller, et al., 1982.

9/ Christensen, et al., 1980.

efficiency of .7 appeared reasonable. From this, the BTU requirements per gallon of ethanol are:

$$87649.67 \text{ BTU/gal} \times \frac{1}{.7} = 125{,}213.81 \text{ BTU/gal}$$

The fuel source for the ethanol production unit is provided as BTU's with a cost per BTU's representative of different fuels. This fuel cost will be varied in order to examine the effects on ethanol production of changing energy costs.

The time that the still could be operating is divided into four periods, December 2 to April 19, April 20 to July 1, July 2 to August 30, and August 31 to December 1. These time periods are chosen so that the competition between field operations and alcohol production can be fully examined. They are also long enough to allow cattle to be brought on and off a DDGS diet without jeopardizing the feed intake of the cattle. The distinctive nature (palatability, taste, and moisture content) of DDGS prohibits frequent intermittent feeding. If fed in this manner cattle will go off feed causing costly weight losses and gastronomic disruptions. Eight to ten weeks is generally accepted as a suitable time period for feeding DDGS.

Labor requirements for the subsystem, a primary subject of inquiry, will be varied in an effort to arrive at the yearly cash flow available to support ethanol production given the various labor demands. Once this yearly cash flow curve is derived a suitable labor requirement is to be fixed into the model for the purpose of conducting subsequent sensisivity analysis.

3.6 Ending Statement

The business of designing a typical farm is somewhat precarious in that one must depend on the work of others. Still, it is this research by others that makes such an endeavor possible. An individual could not hope to conduct all the independsable procedures which pave the road to such "economic engineering" studies as this. This chapter has described a blueprint of a "typical" farm and stated the assumptions made in the effort of providing a realistic representation of farming in the Thumb area of Michigan. The next chapter will report how the model performed under alternative conditions.

CHAPTER IV

MODEL RESULTS AND SENSITIVITY ANALYSIS

4.1 Introduction

The results of running the model are reported in this chapter. The discussion begins with a review of the assumptions and base values used in the model. Next, yearly cash flows available to support the various ethanol production operations are given. Last, the sensitivity of the optimal rate of ethanol production within a year to changes in the price of ethanol and energy is determined.

4.2 Base Values of Inputs and Outputs Used in the Model

In order to depict the most realistic situation for a farming enterprise in the thumb area of Michigan, considerable care is required in selecting the base values used in the model. In cases where there is substantial fluctuation in the monetary value of a commodity within a year, averages are used. Table 4-1 summarizes base values used in the model.

The average price received by farmers in the United States for corn grain in the 1979/80 crop year was $2.50 per bushel as reported in the Feed Situation, October, 1980.[1/] The price of corn in the study area has been approximately equal to the U.S. average in recent years. The cost

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[1/]USDA, 1980.

TABLE 4-1. Base Values Used in the Analysis

Item	Value
Ethanol yield, gal/bu corn	2.5
DDGS yield, lbs of dry matter/bu of corn	17.5
BTU requirements, BTU/gallon moisture free alcohol	126,213
Boiler efficiency, percent	70
Variable cost of alcohol production, $/gal	.20
Life of the still, years	10
Alcohol, 200 proof, $/gal	1.90
DDGS, farmer selling, $/cwt dry matter	Sales Not Permitted
Corn, farmer buying price, $/bu	2.70
Corn, farmer selling price, $/bu	2.50
Soybean meal, (44% crude protein) farmer buying price, $/cwt	12.92
Soybean, farmer sell price, $/bu	6.25
Natural gas, $/100,000 BTU	.234
Diesel, $/gal	1.00
Labor, hired, $/hour	4.00
Labor, farmer's reservation price, $/hour	1.00
Cattle, 450 lb feeder calves, $/cwt[a]	86.60
Cattle, 1050 lb fed steer, $/cwt[a]	60.00
Interest rate, %/per annum	15.00

[a]Returns above feed costs are maintained at a constant value when the price of corn is varied.

of purchasing corn was set $.20 per bushel above the selling price or $2.70 per bushel. The purchase price, on a cost per pound of dry matter basis, is:

$$\$2.70/\text{bu. corn} \div (56\ \text{lbs/bu.} \times 84.5\%\ \text{dry matter}) = \$.057/\text{lb corn dry matter}$$

The average U.S. price of 44% crude protein soybean meal (SBM) for the 1979/80 crop year was $12.92 per hundredweight.[2/] The Michigan State University Agricultural Model reports the price for soybeans at $6.25 per bushel during this same period.[3/] These prices are also near the long-run relative price relationships for soybeans and corn (i.e., the price of soybean meal per pound relative to the price of corn per pound averages 2.3:1 and the price per bushel of soybeans relative to the price per bushel of corn is 2.5:1). The SBM price per pound of dry matter is:

$$\$12.92/\text{cwt} \div 90 = \$.144/\text{lb of SBM dry matter}$$

The price of fuel for drying corn and operating the ethanol subsystem is based on the current cost of natural gas to industrial users. This price, as reported in the Monthly Energy Review is $2.387 per 1000 cubic feet.[4/] A cubic foot of natural gas has 1,019 BTUs. Therefore, the cost per 100,000 BTU is $.234.

The base price of moisture free (less than 0.5% water) ethanol was set at $1.90 per gallon. This choice is a somewhat arbitrary starting

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[2/] Ibid.

[3/] MSU, 1980.

[4/] Monthly Energy Review, October 1980.

point for the analysis but is in line with current prices for 190 to 200 proof ethanol. The average price reported for January through July, 1980, in the Chemical Marketing Reporter for 190 and 200 proof ethanol was $1.78 and $1.90 per gallon, respectively.[5/] The Ag Energy bulletin reported the September 16, 1980 price per gallon of ethanol at three major industrial distillers (ADM, Midwest Solvent, and Publicker) was $1.75/gal.[6/] Also, income tax credits of thirty cents and forty cents respectively for 150 to 190 proof and 190 to 200 proof ethanol raise the effective price by these amounts.

Cattle price are 1979 Michigan averages.[7/] All other inputs such as fertilizer, pesticides, cattle implants, etc. were also recent (1979) average for Michigan.[8/]

4.3 Break-Even Annual Cash Flow Available to Support Ethanol Production

The break-even annual cash flow is defined as the maximum amount this farmer would be able to spend for the capital depreciation and interest charges on an ethanol production system in a year; that is, it is the flow at which depreciation, interest and maintenance are covered and profits (in an economic sense) are zero. It is the maximum amount the farmer would consider spending as an annual amortized payment over the life of the ethanol production equipment.

[5/] Chemical Marketing Reporter, August 1980.

[6/] Ag Energy, Fall, 1980.

[7/] Michigan Agricultural Statistics, 1980.

[8/] Schwab et al., 1980.

An initial run of the LP model is made with ethanol production excluded as a possible activity for the farmer. This run is to be used as the base from which to determine the annual value of an ethanol production unit with various labor requirements. In runs subsequent to the base run ethanol production is allowed to enter as an activity but no cost is entered to represent depreciation, interest charge or maintenance cost of the unit. The calculated difference between the objective functions of these and the base run is the maximum amount a farmer would be willing to pay as an annual amortized payment to support an ethanol production unit with a given capacity and labor requirement.

4.3.1 Break-Even Cash Flow as a Function of Labor Requirements

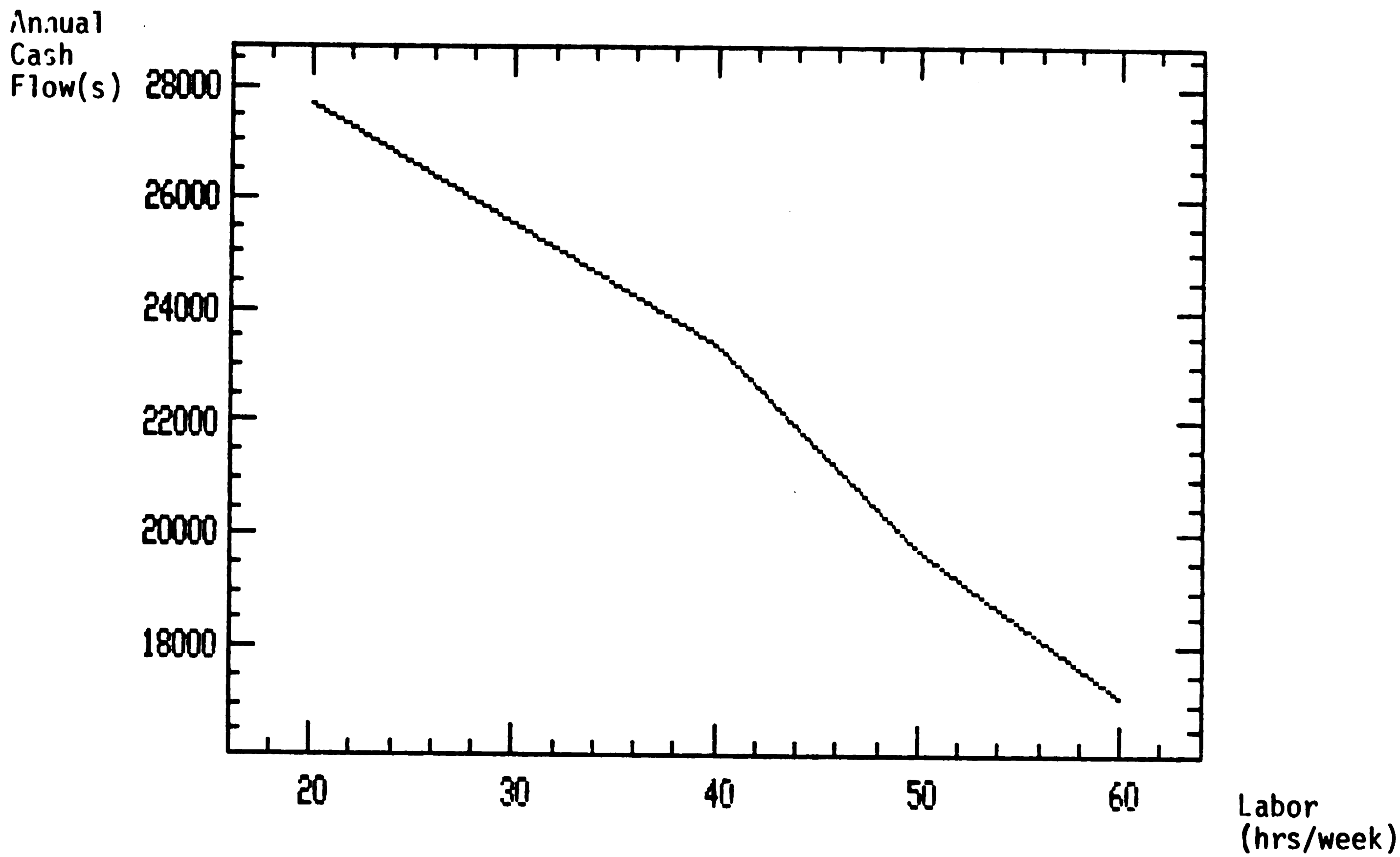
In the preceding chapter, the selecting of "reference" stills is discussed. Two distillation capacities are to be examined; a 100,000 gallon per year unit and a 12,500 gallon per year unit. In order to determine the break-even annual cash flow available to support each of these units, it is necessary to vary the labor requirements because the availability of the farmer's own labor and cost of hiring labor are determining factors. Labor can be hired at $4.00 an hour while the reservation price placed on the farmer's labor is $1.00 per hour. Obviously, the less labor required to produce ethanol, the more a farmer is able to pay for the production unit. Therefore, the labor requirements for the 100,000 gallon still are varied at ten hour per week intervals between 20 and 60 hours per week; the smaller 12,500 gallon unit has labor requirements ranging from 10 to 40 hours per week.

The annual cash flow for the 100,000 gallon ethanol unit, calculated as a function of weekly labor requirements is listed in Table 4-2. A graphic representation of the relationship is in Figure 4-1. For every hour that the labor requirement decreased from a base of 60 hours per week, the annual amortized payment (or cash flow) could be increased by $269.8 a year. The net present value of any system can be deduced by multiplying the annual cash flow by the appropriate factor from Table C.3 in Appendix C. The net present values listed in Table 4-2 are based on the assumptions of real rates of interest of 10% and 15% and 10 years of life for the unit. The net present value represents every physical aspect of the ethanol production system. Maintenance allowances should be made by deducting an appropriate sum from the net present value.

TABLE 4-2. Annual Cash Flows and Net Present Values for a 100,000 Gallon per Year Ethanol Unit for Alternative Labor Requirements

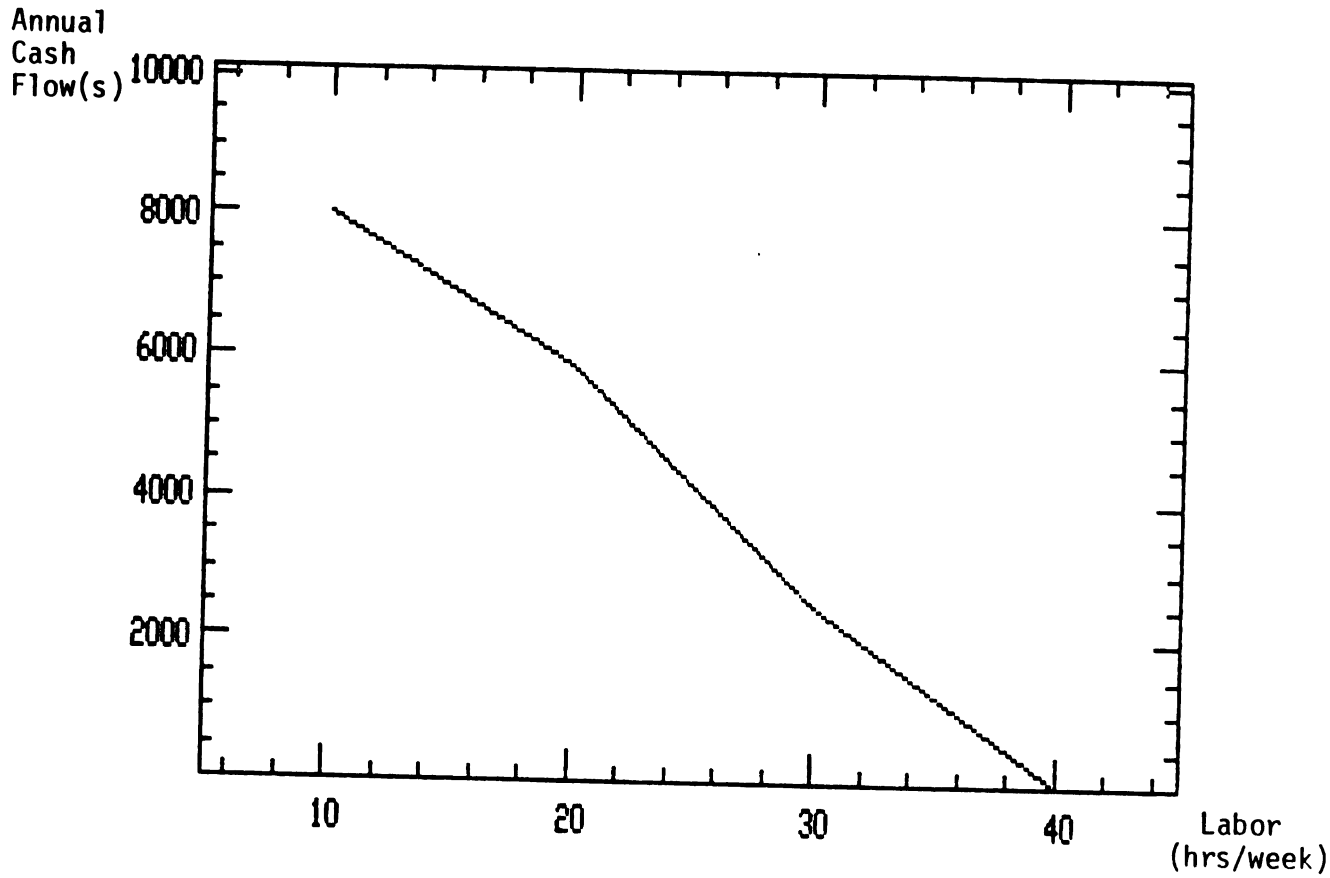
Labor Requirements (Hours per Week)	Annual Cash Flow (dollars)	Net Present Value of the Unit (real rate of interest)	
		10%	15%
20	27,682	170,100	138,930
30	25,545	156,970	128,210
40	23,408	143,840	117,480
50	19,686	120,970	98,800
60	17,121	105,210	85,930

The annual cash flow available to support a 12,500 gallon capacity ethanol production facility showed the same response to labor saving technology as seen in Figure 4-2. Plant size for this smaller unit is



The Maximum Annual Cash Flow Available to Support
a 100,000 gal. per Year Ethanol Production System
Given Alternative Assumptions About Labor Required per Week

FIGURE 4-1



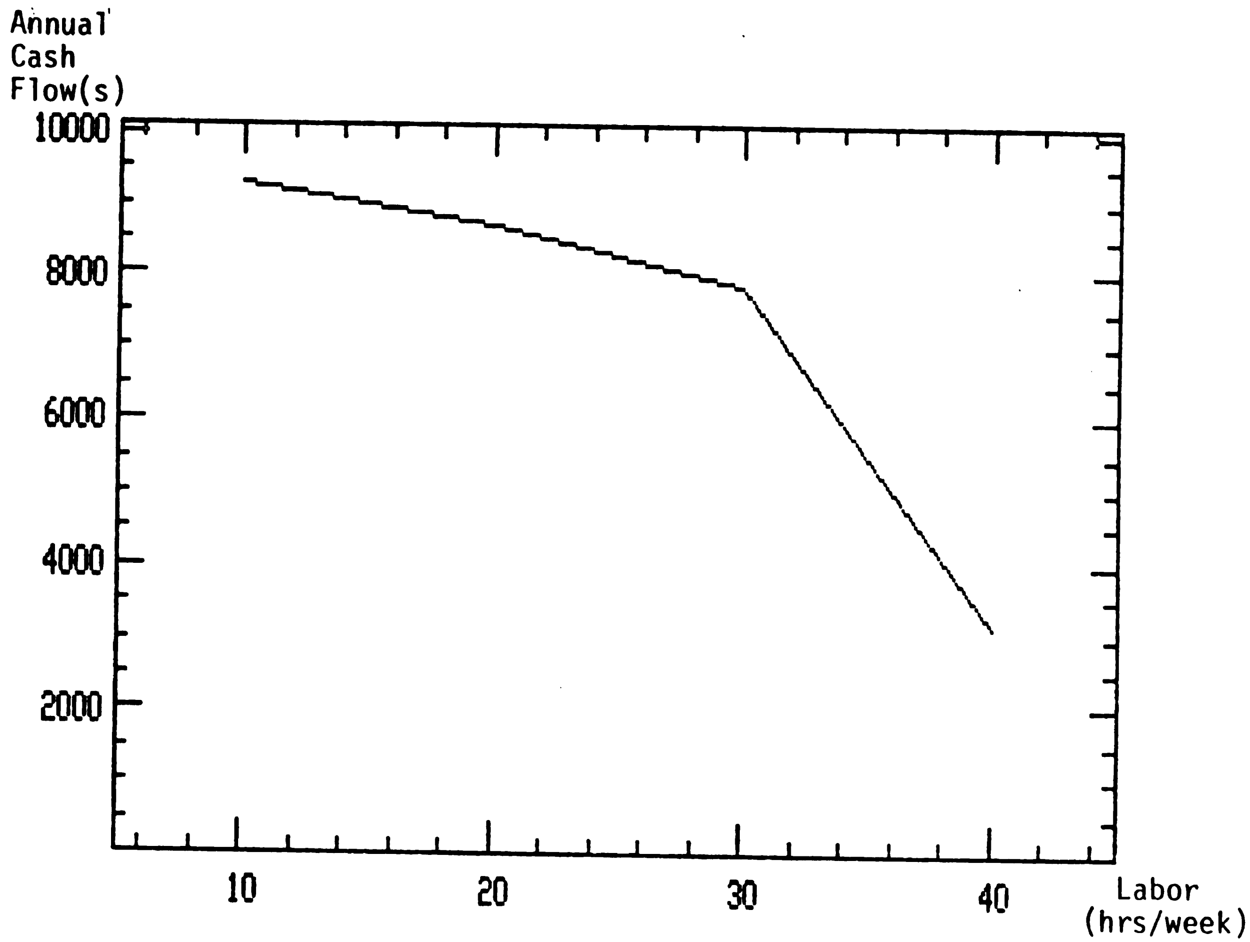
The Maximum Annual Cash Flow Available to Support a 12,500 gal. per Year Ethanol Production System on a Farm with a 1000 Head Feedlot Given Alternative Assumptions About Labor Required Per Week

FIGURE 4-2

designed to supply all the liquid fuel needs to carry out the farming activities. For each hour reduction in labor required, the farmer would be able to spend $273 more a year to support the ethanol production system at the break-even level of operation. The economic impact of changing labor required on the annual cash flow available to support ethanol production is comparable across size of unit when farmer labor availability is not changed.

When the feedlot size is limited to 125 cattle, the number of cattle needed to consume all of the distillers grains from the smaller unit, the annual cash flow available for ethanol production changes considerably (Figure 4.3). From ten to 30 hours of labor required per week, a one hour reduction in labor needs reduces the annual use cost by $71. From 30 to 40 hours of labor required per week, a one hour reduction is worth $471 per year. It is worth a great deal to the farmer for an ethanol production system to be designed requiring 30 hours of labor each week as opposed to 40 hours, but it is worth relatively little to reduce labor requirements much below 30 hours per week. The farmer does not have to hire any labor for ethanol production as long as it requires thirty hours of labor or less each week. As soon as the farmer has to hire labor for ethanol production, the yearly cash flow the farmer is able to support drops drastically. Freeing up the farmer's labor by reducing the feedlot size from 1000 head, which would require 80% of his time, to 125 head dramatically demonstrates this point.

The annual cash flow and net present values (again based on 10 years of life and 10% and 15% real interest rates) for the 12,500 gallon system with full (1000 head capacity/year) and limited (125 head capacity/year) cattle production are presented in Table 4-3. Comparing full and



The Maximum Annual Cash Flow Available to Support a 12,500 gal. per Year Ethanol Production System on a Farm with Limited Cattle Production Given Alternative Assumptions About Labor Required per Week

FIGURE 4-3

TABLE 4-3. Annual Cash Flow and Net Present Values for a 12,500 Gallon Ethanol System with Full and Limited Cattle Feeding for Alternative Labor Requirements

Labor Requirements (Hours per Week)	Annual Cash Flow		Net Present Value			
			10% Real Interest		15% Real Interest	
	Full	Limited	Full	Limited	Full	Limited
10	8001	9292	49,170	57,100	40,160	46,640
20	5883	8649	36,150	53,150	29,530	43,410
30	2475	7871	15,210	48,370	12,420	39,500
40	21	3162	130	19,430	105	15,870

limited cattle production scenarios is similar to comparing an enterprise where farmer labor availability is constraining with one where it is not. A review of commercial ethanol production units of this capacity (costing between $30,000 and $40,000 with very little automation) with respect to the net present values in Table 4-3 suggest that unless a farmer has a great deal of low valued labor available he will not be able to afford to produce ethanol merely to meet his liquid fuel needs.

4.3.2 Break-Even Cash Flow as a Function of Energy Requirements

The energy required to produce one gallon of ethanol using the "reference" still developed in Chapter III is 125,214 BTU. This value represents the use of state-of-the-art technology but there is a considerable effort being made to reduce these requirements. Therefore, it would be interesting to know how the yearly cash flow available to support ethanol production changes when there are reductions in the amount of energy needed to produce a gallon of ethanol.

In order to examine the energy requirements alone, it is necessary to "fix" in labor requirements. For the 100,000 gallon yearly capacity still, a forty hour work week is used; the 12,500 gallon unit has labor demands set at 30 hours per week. These labor requirements are used in all subsequent sensitivity analysis. Energy requirements are lowed to 80%, 60%, 40% and 20% of the base of 125,214 BTU per gallon of ethanol produced. Table 4-4 and Figure 4-4 illustrate the relationships between yearly cash flow and energy requirements for both ethanol production capacities.

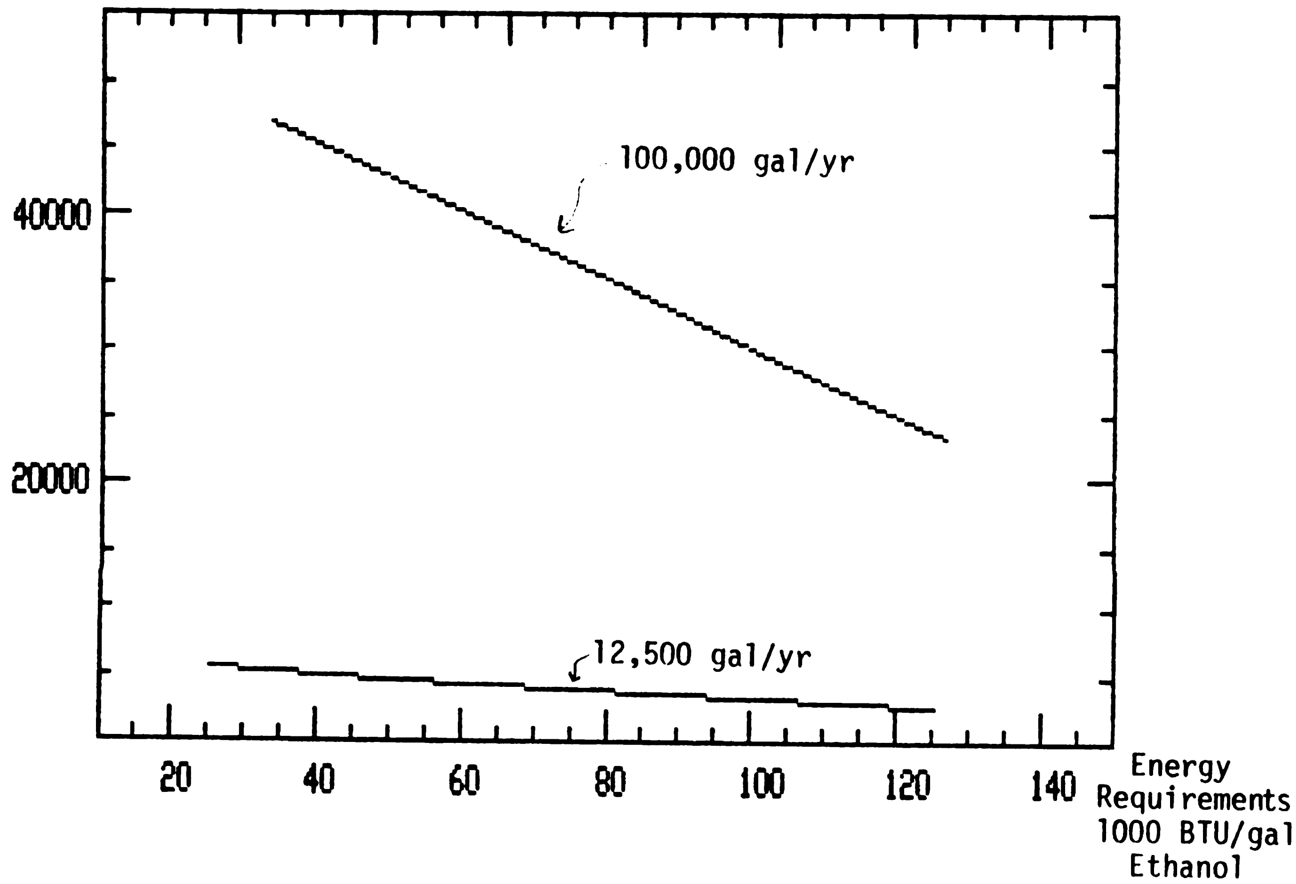
TABLE 4-4. Annual Cash Flow for a 100,000 Gallon per Year and 12,500 Gallon per Year Ethanol Production Units for Alternative Energy Requirements

Energy Requirements (BTU/gallon of ethanol	Yearly Cash Flow 100,000 gallon unit	12,500 gallon unit
125,214	23,408	2,475
100,171	29,273	3,209
75,128	35,138	3,943
50,086	41,003	4,677
25,043	46,868	5,411

For each decrease of one BTU per gallon of ethanol produced, the annual cash flow available to support the 100,000 gallon per year ethanol subsystem increases by $.2432 (stated differently, a 1000 unit reduction in BTUs required per gallon increases the annual cash flow available by $243.20). The impact is much smaller for the case where only enough ethanol was produced to meet the farm fuel requirements. A one BTU per gallon reduction in energy requirements increases the annual cash flow available by $.0293 (or $2.93/1000 BTU savings). Not only does the opportunity exist to save more energy per gallon of output in larger capacity units because of scale efficiencies inherent in heat recovery equipment, but it also pays more in absolute terms to do so. The same situation holds true for all variable costs of ethanol production.

4.4 Sensitivity of Production Levels Within a Year

The production of ethanol within a year will vary as its profitability varies. Two prices that directly affect this profitability are the price of ethanol and the price of energy to fuel the ethanol production



The Maximum Annual Cash Flow Available to Support Both Ethanol Production Systems Given Alternative Assumptions About Energy Use per Gallon of Ethanol Produced

FIGURE 4-4

system. For this analysis the annual cash flow is divided into an interest and a depreciation-maintenance cost. Assumptions other than the aforementioned labor requirements must also be "fixed" into the model in order to carry out the analysis; a real interest rate of 15% and ten years of life are used.

To divide the interest cost from the depreciation-maintenance cost, the yearly cash flow is first multiplied by ten, the life span of the equipment. Next, the net present value is subtracted from this product. The resulting value is the amount of interest to be paid out over the life of the ethanol production unit. Dividing the total interest paid by ten gives the annual interest payments. Once an ethanol production unit is purchased, this annual interest cost is incurred regardless of its level of operation.

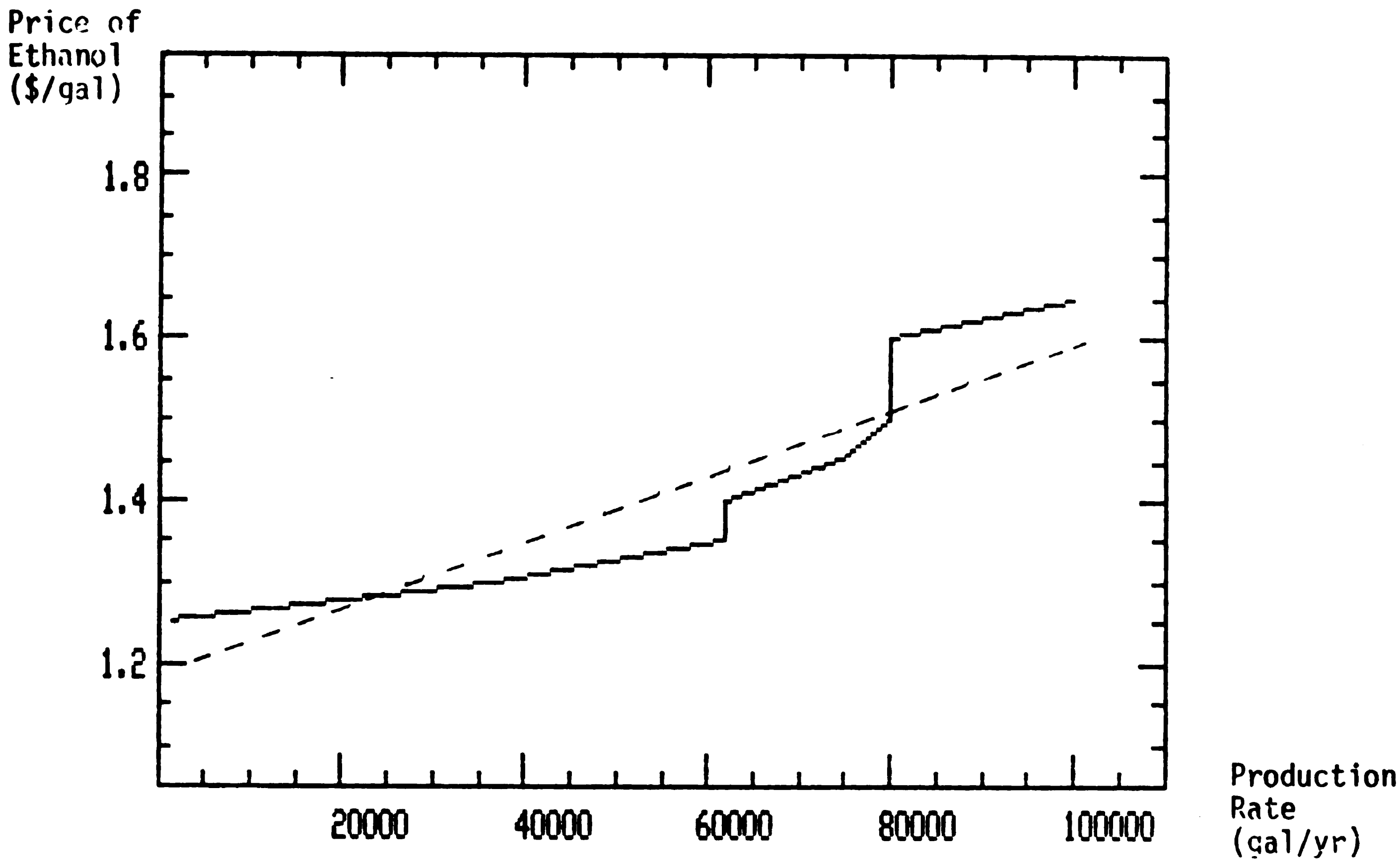
There is no consensus in the literature regarding the useful life of an ethanol production unit. Ten years of life is acceptable for a stainless steel unit used at or near full capacity for that time span. Because production levels less than full capacity are being examined here, it is assumed that depreciation and maintenance costs are a function of the units use. Therefore, these costs are incurred only during the periods within a year when ethanol is being produced (e.g. a unit with an expected life of 10 years will last 20 years if used only half the time).

Production in each period is an all or nothing decision in order to avoid problems of intermittent feeding of DDGS; thus ethanol production is entered as binary variables in the model and mixed integer solution algorithm is used. Conventional linear programming sensitivity analysis techniques are no longer appropriate. Several different pricing relationships are examined and graphed. Each step in the graph is the result of either shutting down or starting up operation of the ethanol production unit in a given period. The broken line gives an approximation of the production rate had it been on a continuous scale.

4.4.1 Production Rate Within a Year as a Function of the Price of Ethanol

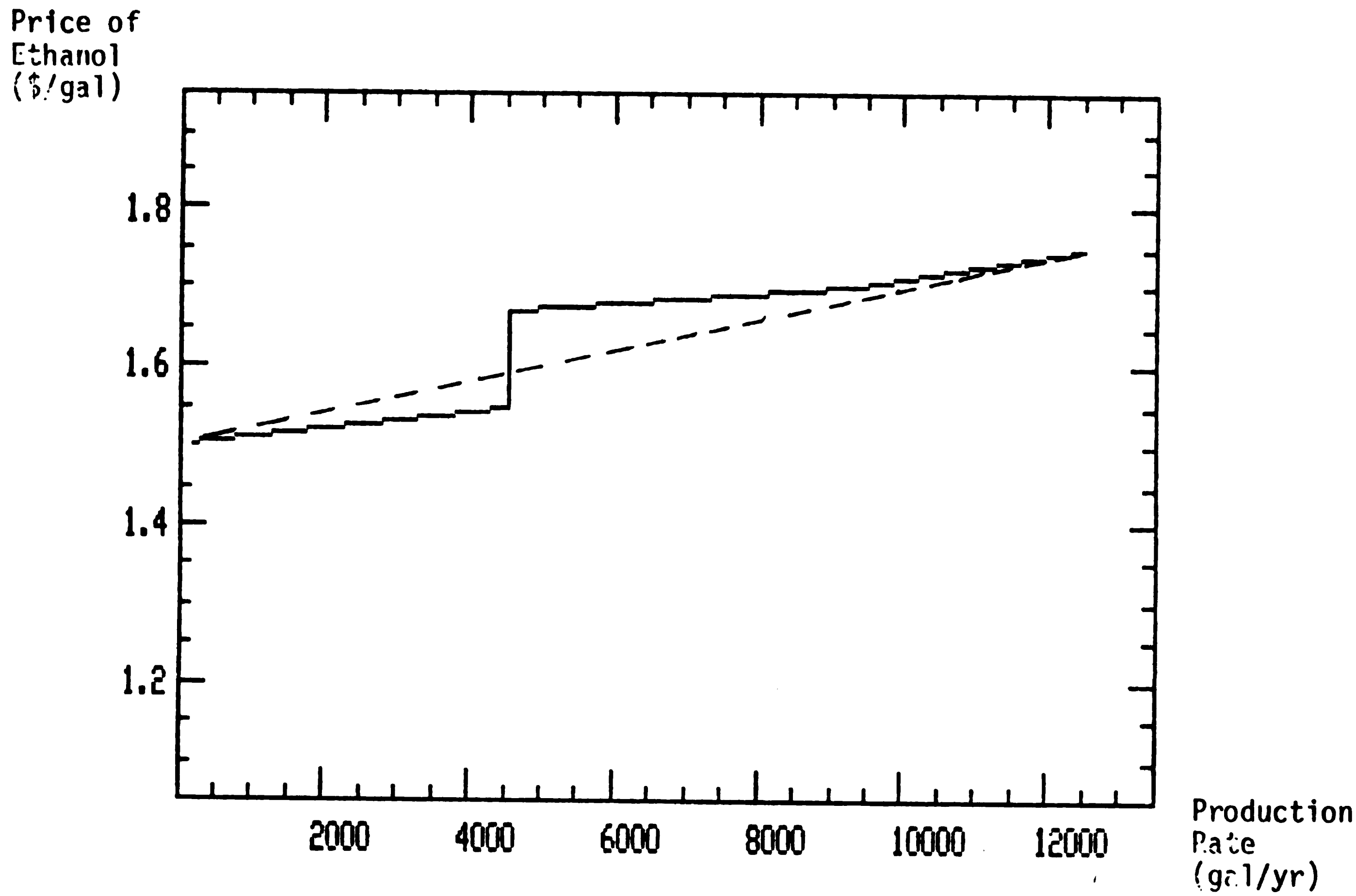
The graph of the production rate of the 100,000 gallon unit as a function of the price of ethanol (Figure 4-5) indicates that some production will occur as long as the ethanol price is at least $1.25 per gallon. Full production takes place when ethanol is priced at $1.65 per gallon or above. For every one cent increase in the price of ethanol there is a 2173 gallon increase in production on a continuous scale. The lower broken line gives one a "feel" for the production rate vs. alcohol price relationship with the present forty cent per gallon of 190 to 200 proof alcohol tax credits available. Zero production would occur at $.85 per gallon rather than $1.25 per gallon.

The best way to examine the analysis of the smaller ethanol production unit is to compare a system with full cattle production with one where cattle production is limited to 125 head. When the ethanol units are entered into the model with their respective maximum cash flows, the operation with a 1000 head feedlot begins producing ethanol when the price of ethanol reaches $1.50 a gallon and is at full capacity when the ethanol price is at or above $1.75 per gallon (Figure 4-6). The subsystem with only enough cattle to consume the DDGS begins producing ethanol when the ethanol price is at a lower, $1.35 per gallon, level and reaches full production as soon as the price hits $1.70 a gallon (Figure 4-7). However, when the same interest charge and depreciation-maintenance cost as for the large feedlot farm is entered into the model for the farm



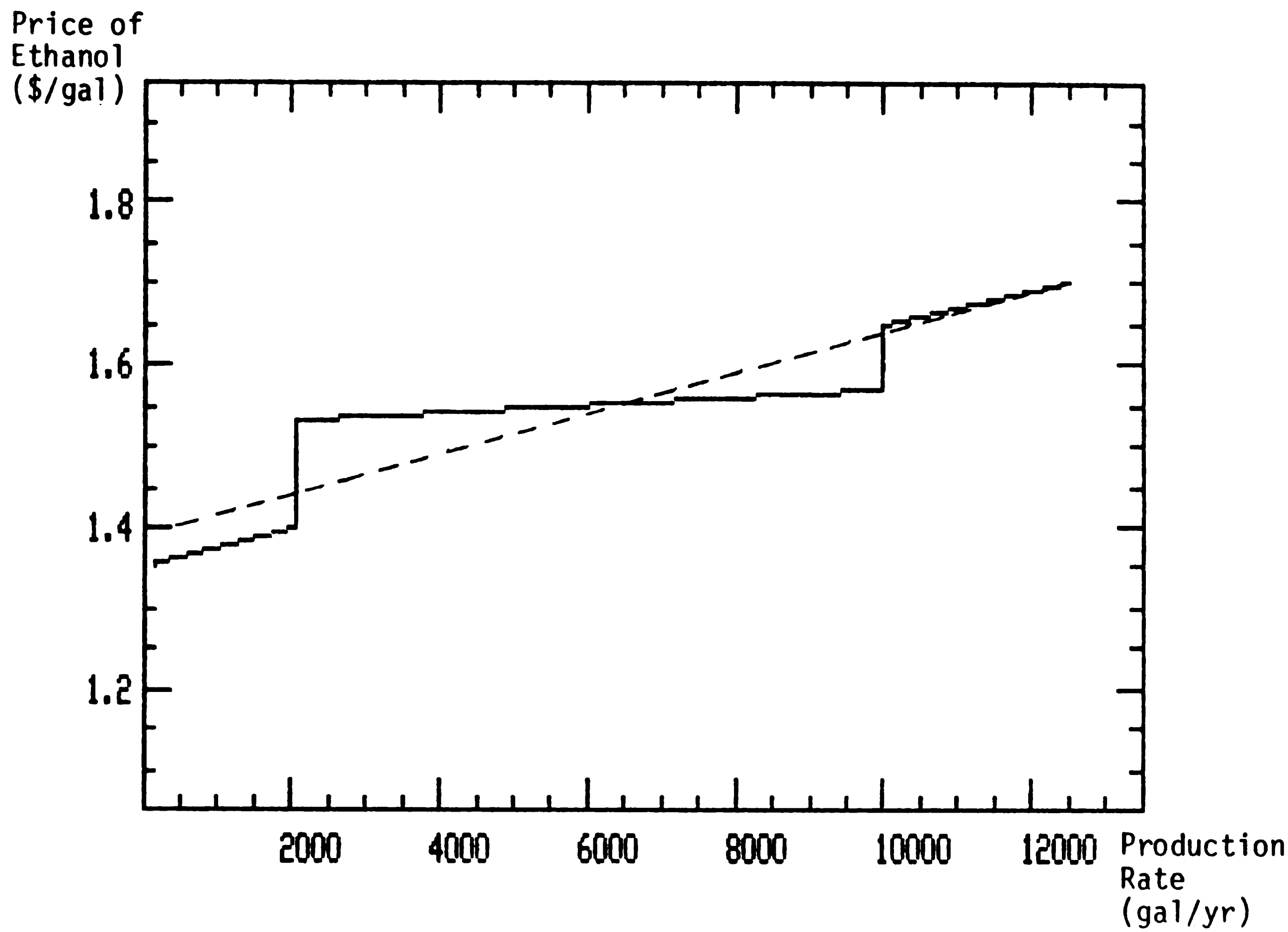
Production Rate as a Function of the Price of Ethanol for a 100,000 gal. per Year Ethanol Production System

FIGURE 4-5



Production Rate as a Function of the Price of Ethanol for a 12,500 gal. per Year Ethanol Production System on a Farm with 1000 Head Feedlot

FIGURE 4-6



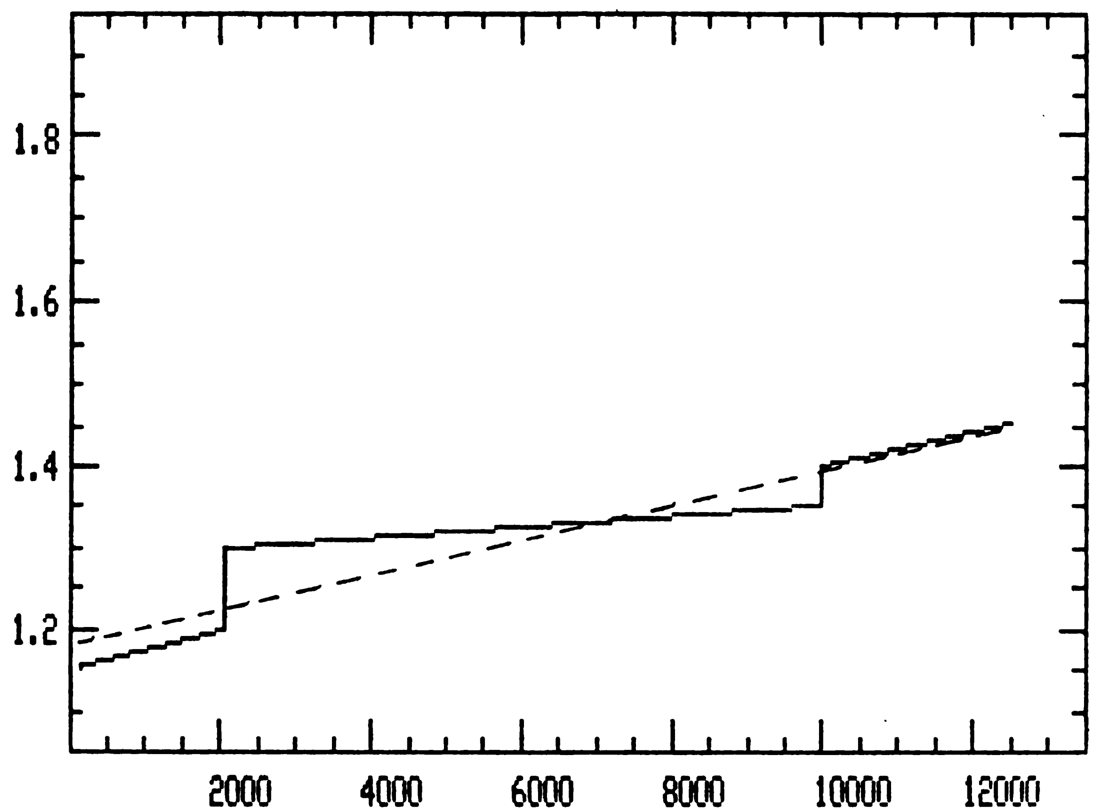
Production Rate as a Function of the Price of Ethanol for a 12,500 gal. per Year Ethanol Production System on a Farm With Limit Cattle Production

FIGURE 4-7

with limited cattle production, the farmer will produce ethanol as long as the price per gallon is at or above $1.15 (Figure 4-8). Full production occurs at $1.45 per gallon of ethanol. With the forty cent tax credit, this farmer could start to replace his diesel use with ethanol when diesel is priced between $1.20 and $1.68 per gallon, depending on the price of ethanol.

The broken lines in these graphs (Figures 4-6, 4-7 and 4-8) indicate that the lack of farmer labor causes the production rate to be much more sensitive to change in the price of ethanol. The farms with the large feedlot displayed a 630 gallon change in the level of ethanol production with a one cent shift in ethanol price; when the cattle enterprise is limited, there is only a 380 gallon change per penny shift in ethanol price. When the ethanol unit on the farm with limited cattle production is charged the same as the one with 1000 cattle, there is a 450 gallon alteration in production level for a one cent movement in ethanol price, but it should be remembered that production starts and full capacity is reached at much lower ethanol prices.

One should be aware that in the cases where there is a large cattle enterprise and very little excess farmer labor, the model shut down ethanol production such that the reduction in production is most gradual. On the other hand, when there is limited cattle production the model first shut down still operations in the spring when the timing of planting activities is most critical to crop yields and continues by ending ethanol production in the fall next, when harvesting causes serious labor bottlenecks. There is a great deal of tolerance for changes in pricing relationships between the ending of fall and spring ethanol production



Production Rate as a Function of the Price of Ethanol for a 12,500 gal. per Year Ethanol Production System on a Farm with Limited Cattle Production but with the Same Cash Flow as with a 1000 Head Feedlot

FIGURE 4-8

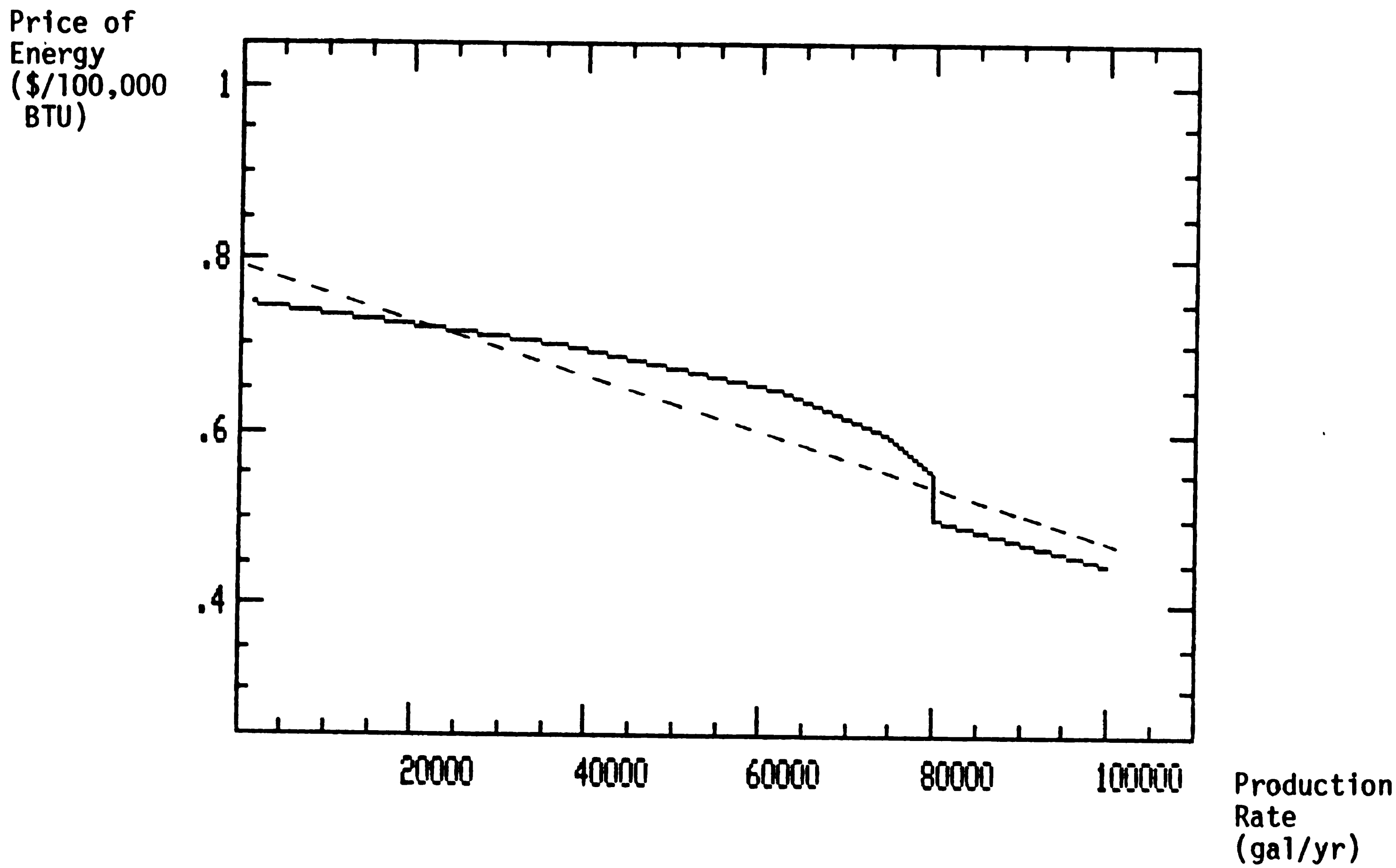
and the ending of winter and summer ethanol production. Table 4-5 illustrates the sequence of shutting down ethanol production as ethanol price decreases.

4.4.2 Production Rate Within a Year as a Function of Energy Price

As the price of energy to operate the ethanol production system rises, ethanol production shuts down as variable costs and depreciation-maintenance costs can no longer be covered. Ethanol price is set at $1.90 per gallon. Production for the 100,000 gallon capacity distillation unit is at full capacity as long as the price of energy does not exceed $.45 per 100,000 BTU (Figure 4-9). For comparison, #6 residual oil is currently selling for about $.40 per 100,000 BTU. Ethanol production stops as soon as the price of energy to fuel the unit reaches $.75 per 100,000 BTU. On a continuous scale, the production rate falls 3572 gallons for every cent increase in the energy price per 100,000 BTU.

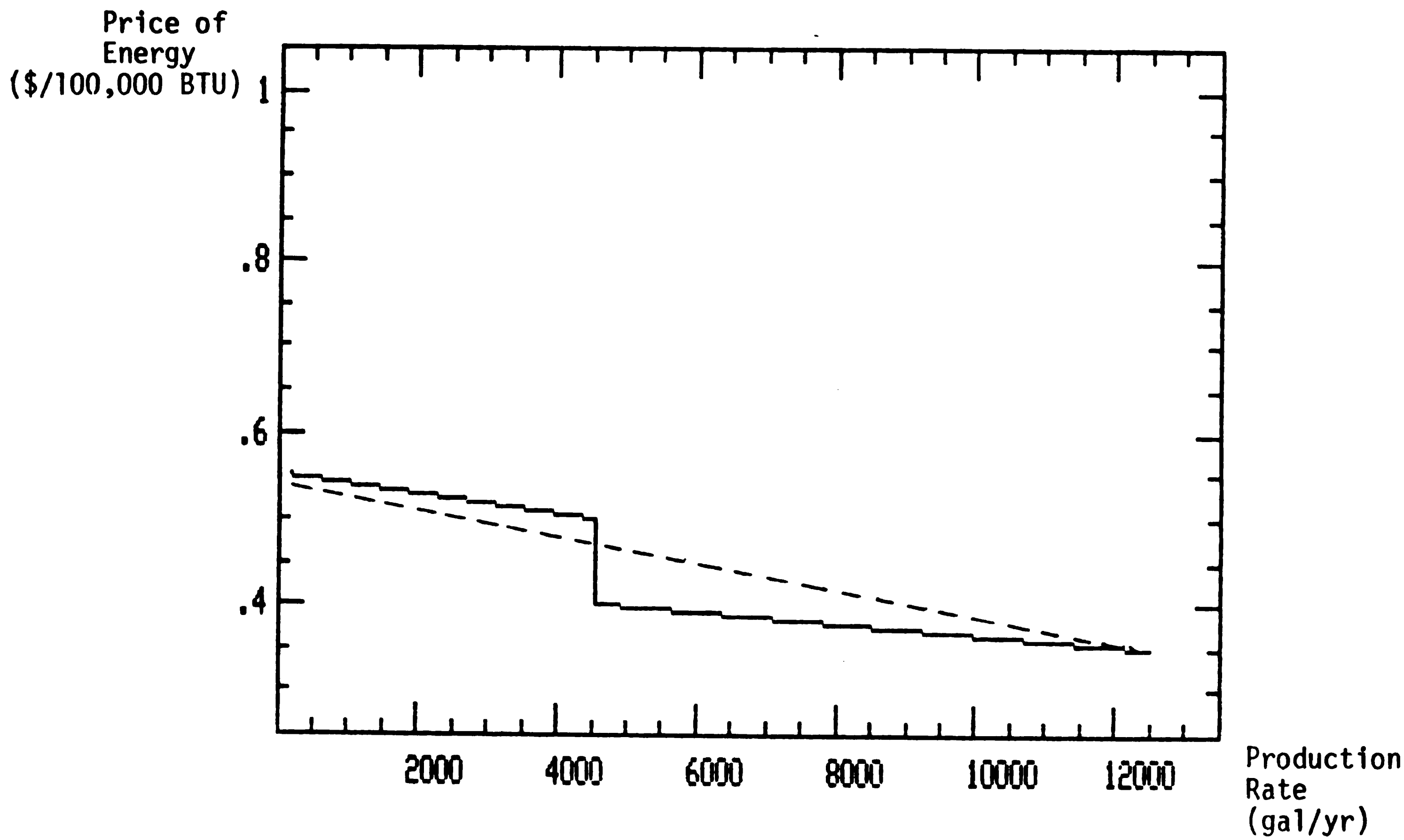
When the small still is used, the results again favor the farming operations with limited cattle feeding (Table 4-6 and Figures 4-10, 4-11 and 4-12). The operation with a 1000 head feedlot produces ethanol at full capacity only up to an energy price below the comparable price of #6 residual oil. Also, the production rate is quite sensitive to changes in the energy price, decreasing production by 630 gallons per year when there is a cent rise in the cost of energy (100,000 BTU). No ethanol production occurs when the price of energy hits $.50 per 100,000 BTU.

On the other hand, when cattle production is limited, the 12,500 ethanol subsystem operates at full capacity as long as the energy price



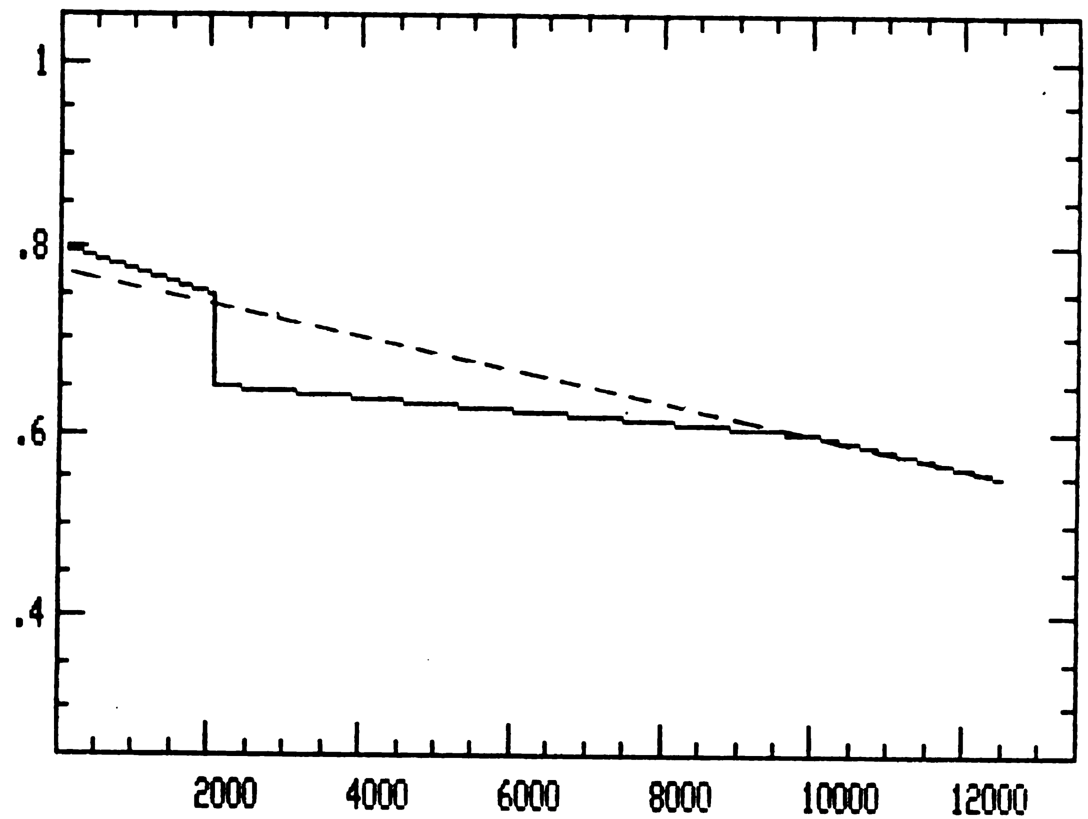
Production Rate as a Function of the Price of Energy for a 100,000 gal. per Year Ethanol Production System

FIGURE 4-9



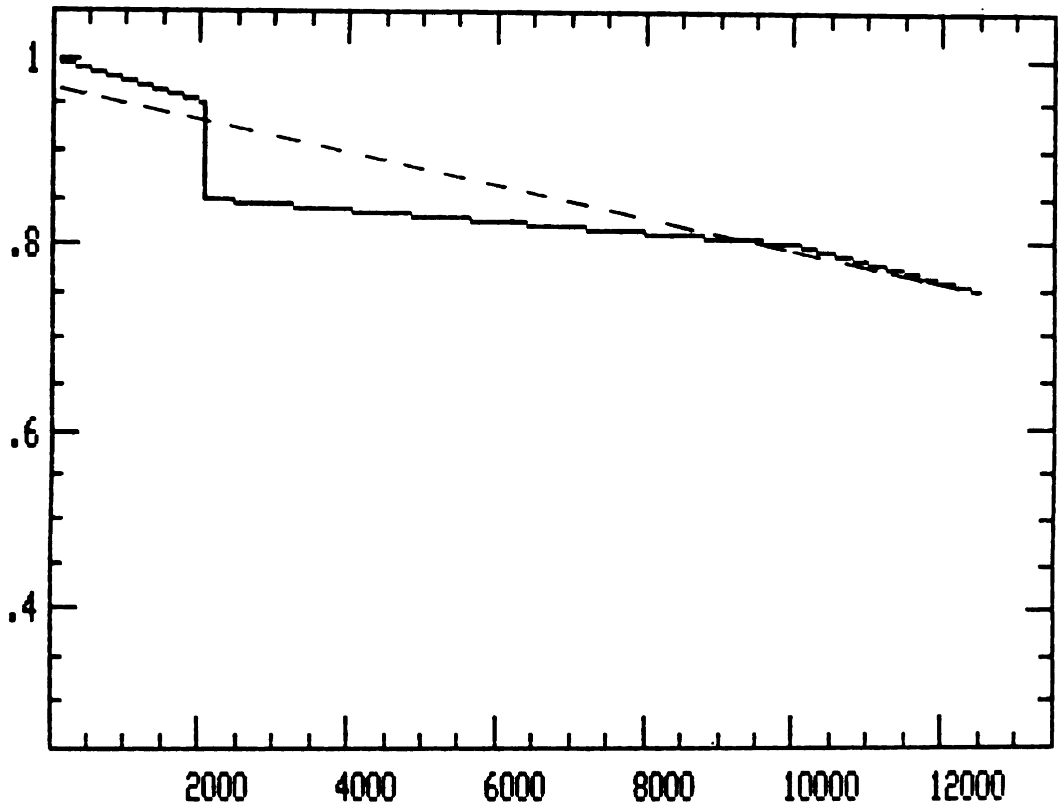
Production Rate as a Function of the Price of Energy for a 12,500 gal. per Year Ethanol Production System on a Farm with a 1000 Head Feedlot

FIGURE 4-10



Production Rate as a Function of the Price of Energy For a 12,500 gal. per year Ethanol Production System on a Farm with Limited Cattle Production

FIGURE 4-11



Production Rate as a Function of the Price of Energy for a 12,500 gal. per Year Ethanol Production System on a Farm with Limited Cattle Production but with the Same Cash Flow as with a 1000 Head Feedlot

FIGURE 4-12

TABLE 4-5. Production by Periods for all Scenarios as a Function of Ethanol Price

Anhydrous Ethanol Price	Winter	Spring	Summer	Fall
1.90	X 0 * +	X 0 * +	X 0 * +	X 0 * +
1.80	X 0 * +	X 0 * +	X 0 * +	X 0 * +
1.70	X 0 * +	X 0 * +	X 0 * +	X * +
1.60	x * +	0 +	X 0 * +	X * +
1.50	X +	+	X * +	X +
1.40	+	X	X * +	X +
1.30		X	X +	
1.20			+	

X - 100,000 gallon capacity

0 - 12,500 gallon capacity; full cattle

* - 12,500 gallon capacity; limited cattle

+ - 12,500 gallon capacity; limited cattle but with less expensive ethanol unit

TABLE 4-6. Production Rate of the 12,500 Gallon Ethanol Operations as a Function of Energy Price

Cattle Feeding	Production Levels Full Production	$/100,000 BTU No Production	Change in Production per Unit Change in Energy Price
Full Cattle (1000 head one time capacity)	35	50	625 gal
Limited Cattle	55	80	530 gal
Limited Cattle but with Less Expensive Ethanol Unit	75	100	530 gal

is at or below \$.55 per 100,000 BTU. When the less expensive unit is used (same ethanol production unit as used for the large feedlot enterprise), full ethanol production continues until energy prices exceed \$.75 per 100,000 BTU. Both limited cattle feeding scenarios exhibit the same rate of change (530 gallons per one cent shift in 100,000 BTU energy price) over their respective ranges but as previously noted, the less expensive unit produces when energy prices per 100,000 BTU are \$.20 above those curtailing production in the more expensive unit. Energy cost must hit \$1.00 per 100,000 BTU before production ends in the less expensive still.

4.5 Ending Statement

When compared with the ethanol units present on the market, the yearly cash flows for the 100,000 gallon ethanol unit appears to be the most logical investment particularly in view of the present tax breaks offered as incentives for alcohol production investment. (These will be dealt with more fully in the next chapter.) As for the smaller still it seems highly unlikely that the farmers whose time is tied up with other more profitable enterprise would ever invest in such small scale production unless the labor requirements were ten hours a week or less. In view of the systems being sold today, this degree of automation would drive the price well beyond that which this farmer could support.

The smaller still on a farm with available farmer labor, on the other hand, may be workable at present costs if the ethanol can be sold or if diesel prices rise to over the two dollar per gallon. If the ethanol can not be sold the farmer would be paying a premium of \$.80 to \$1.20 per gallon of fuel used for the insurance of being energy self-sufficient.

If production units can be obtained within the limits set by the yearly cash flows, production would continue as long as the fuel could be sold, the $.40 per gallon credits are in place, and the energy price remains below $.35/100,000 BTU. As energy prices rise only the larger capacity operations which are able to reduce energy needs the the small plants on farms with excess labor will be producing. Again, small units meant to make the farmer energy independent do not appear promising.

Finally, it is not unlikely that farmers who do have the time to run their own stills will operate those stills only during slack seasons. The value of the distillers grains was between $.062 and $.068 per of dry matter. Using the average of $.065 per pound of dry matter this amounts to a credit of $5688 per year for the smaller still and $45,500 per year for the 100,000 gallon still. The importance of utilizing this by-product can not be understated.

CHAPTER V

IMPLICATIONS OF THE MODEL RESULTS AND CONCLUSIONS

5.1 Introduction

In this study, it has been demonstrated that on-farm ethanol production is a questionable enterprise for a farmer to undertake, even under the best conditions. This final chapter highlights the key results in order to draw implications and conclusions of the research. Next, the implications of the information for farmers and policy makers are deduced. The chapter concludes with a discussion of the scope of applicability of the study and research needs.

5.2 Problem and Research Methodology Review

With the growing interest in the use of renewable agricultural resources for the production of fuel, the Michigan farmer justifiably is wondering what role he might play in this potential industry. Also, farmers become excited about the prospect of an additional market for their produce. Persistent uncercainty in commodity markets has lead to a declining confidence in the system and subsequent desire to maintain as much control of their own destiny as possible. A logical sequence to this line of thinking would be to produce and use or sell ethanol directly from the farm. Such an arrangement might enable the farmer to establist a degree of energy self-sufficiency, while increasing their profits. The efficacy of such an endeavor has been the central issue of the thesis.

Linear programming is used as a tool in a whole farm budgeting approach. The relationship of farming activities within the LP model are established so that the effects of introducing an ethanol production subsystem can be examined. Most investigations have used a partial budgeting framework and have evaluated profitability based upon the estimated market price of ethanol production systems. Because of the large amount of variability in manufacturers' price and performance claims the approach taken here used only those physical attributes which are fairly well established and asked the question "How much could a farmer spend as a yearly amortized amount to support an investment in an ethanol production unit?"

This yearly sum represents the depreciation and interest charges on the capital asset. All other costs (e.g., chemicals, energy to power the system, insurance, labor, taxes) are separate items in the model. Two still capacities are chosen for examination; 12,500 and 100,000 gallons/year. Since drying the byproduct is expensive and since marketing the wet byproduct can be difficult the largest still was constrained in size by the amount of wet byproduct that could be consumed by a 1000 head one time capacity feedlot. The second capacity was one which would provide enough liquid fuel to carry out the farming operations. The smaller unit is examined both with the large feedlot and with the number of cattle limited to that amount which could just consume the byproduct.

There has been much controversy over labor and energy requirements of ethanol production. Accordingly, the yearly cash flow available to support an ethanol subsystem is calculated varying these two components. The resulting relationships made it possible to draw conclusions concerning the feasibility of adding an ethanol subsystem to the farming system from what is known about prevailing production units (e.g., capital cost, labor and energy requirements) and interest rates.

Upon conclusions of this the size ethanol unit is fixed in the model and the appropriate depreciation and interest costs charged. The selling price of ethanol and the buying price of energy to operate the ethanol production unit (i.e., BTU's) could be varied to ascertain the sensitivity of production within a year as a function of these two variables.

5.3 Review of Model Results

Aspects of the analysis of the larger capacity unit will be surveyed followed by a recapitulation of the analysis of the smaller ethanol unit. For ethanol production units producing 100,000 gallons per year, the farmer could afford between $17,000 and $27,500 annually for units requiring between 60 and 20 hours of labor per week. For every hour per week that the labor requirement was reduced, the farmer could pay $270 per year more in annual use costs to support an ethanol unit. For changes in the energy requirements per gallon of ethanol produced, the farmer could afford to increase his yearly support payment by the amount equal to absolute values saved by reducing the energy requirement. This absolute amount is a function of the price of energy and the capacity of the unit.

Given a capital cost of $23.4 thousand per year and require 40 hours of labor per week the 100,000 gallon unit continued at full capacity as long as the price of alcohol remained above $1.65/gallon and the cost of energy to run the production unit is below $.45 per 100,000 BTU. No production occurred (i.e., it is more profitable to incur the interest charges and let the unit stand idle) when the price of alcohol falls below $1.25 per gallon or the price of energy rises above $.75 per 100,000 BTU. For every one cent change in the price of alcohol, there is a 2200 gallon change in the same direction in the production level within the range stated above. For energy price, there is a 3200 gallon change in production in the opposite direction for every one cent alteration in the cost of 100,000 BTU's of energy to run the still.

The results for the smaller production unit include both the full cattle and limited cattle scenarios. The annual cash flow as a function of labor requirement for the unit with full cattle production ranged between a yearly cash flow of $8,000 for a unit requiring 10 hours of labor per week and only $21 for the unit using 40 hours of labor per week. The farmer could afford to pay $273 more per year to support ethanol production for every hour of labor saved. In contrast, the smaller unit on a farm with a cattle population just large enough to consume the byproduct could justify an annual use cost of $9300 per year if only 10 hours per week of labor were required and $3200 per year if 40 hours per week of labor is needed for ethanol production. Although these two figures represent the extremes examined, the unit without full cattle production exhibits a radical change in annual cash flow between the 30 and 40 hour per week units. This is due to the need to hire outside labor for the more labor intensive operation. The analysis for the energy requirements is identical to that of the larger ethanol production subsystem.

Production level within a year as a function of changing ethanol and energy prices is less sensitive for the production unit on the farm with limited cattle production. On this farm, full production took place as long as the price of ethanol is above 1.70 per gallon as opposed to 1.75 for the farm with a large feedlot. Production is curtailed on the farm with limited cattle at $1.35 per gallon of ethanol while production ended at $1.50 per gallon on the full cattle farm. Likewise, changes in energy costs yield similar results as can be seen in Table 4-3.

To avoid falsely concluding that these results are solely due to labor availability, the same depreciation and interest cost are entered for both operations. The runs show that ethanol production continued throughout an even greater range of ethanol and energy prices for the limited cattle farm. The production level within a year varied between $1.45 and $1.15 per gallon of ethanol and between $.75 and $1.00 per 100,000 BTU's of energy. In other words, ethanol production will occur on the farm at lower ethanol prices and higher energy prices as long as labor does not have to be hired to operate the ethanol production unit.

5.4 Implications of the Research for the Farmer

The implications for farmer decision making must be viewed in context with the existing market for ethanol production equipment and current institutional incentives. Manufacturers and dealers of ethanol production equipment rely on various technologies to offer a wide range of possible unit configurations representing varying performance claims and prices. Some generalities will have to be drawn before the research results can be effectively applied to farmer decision making.[1/]

[1/] Generalizations about the ethanol equipment market are based on a survey of ethanol equipment manufacturers and dealers conducted by the author.

5.4.1 Implications for the Farmer Considering Small Scale Ethanol Production

There are ethanol production units being marketed ranging from 1000 gallons of ethanol per year capacity to several million gallons per year capacity. The smaller units (1,000 to 15,000 gallons per year capacity) tend to be extremely labor intensive (1 hour per 5 to 15 gallons of alcohol produced) batch units that are inexpensive, (from $.70 to 1.95 per gallon of yearly capacity). These "hobby stills," as they are often referred to, seldom product over 180 proof alcohol and offer little opportunity for energy efficient production. They afford the farmer interested in maintaining a degree of energy self-sufficiency the opportunity to do so for a relatively small initial investment. Yet, this apparently low cost is misleading.

First of all, since the final product is less than 180 proof and sometimes as low as 120 proof, the ethanol must be used straight in the farmers engines. The cost of retrofitting of engines must be included as part of annual cash flow and after the change over is made, the farmer is unable to efficiently use fuels other than alcohol. One dependence is exchanged for another.

A second and even higher expense is the premium over the cost of conventional fuels use of home produced ethanol entails. At gasoline prices of $1.35 a gallon, the farmer will be paying $.98 per gallon to replace gasoline use with $1.90 per gallon ethanol. For $1.20 per gallon diesel the premium would be $1.43 per gallon of replacement. (The replacement values were calculated on a BTU basis with the $.30 federal tax credit in place.) More likely the lower proof ethanol will be sold to a large distillery for redistillation.

TABLE 5.1 Comparisons of Net Present Values for a 12,500 Gallon Ethanol System with Tax Credits

Labor Requirement Hours/Week	With Cattle		Without Cattle	
	15% Interest	10% Interest	15% Interest	10% Interest
10	50,200	61,500	58,300	72,100
20	30,700	45,200	54,400	66,400
30	15,500	19,000	49,400	60,400
40	131	161	19,800	24,300

The deciding factor may very well be the availability of time for operation of the ethanol subsystem. As can be seen in Table 4-2 the annual cash flow available for support of the ethanol unit on the farm with the large feedlot is substantially below that of the farm with the limited number of cattle at levels above 20 hours of labor per week. The inclusion of even minimal controls will drive the price of the equipment well above that which can be supported. South Dakota State University reported the replacement cost of their ethanol production unit with a capacity of 9,088 gallons per year as being around $90,000. Labor requirements for that particular still were 14 hours per week.

There is, however, a ten percent federal tax credit available for the purchase of "alternative energy property" which when coupled with the permanent business investment tax credit of ten percent can substantially boost the amount a farmer can pay for the production unit, retrofitting machinery, and other necessary adjustments. The values in Table 5-1 compare the net present values of these assets when the tax credits are included. Depreciation is calculated over a ten year life span.

The energy property tax credit expires December 31, 1985, but to be eligible after January 1, 1983, the equipment used to convert biomass to alcohol must use a primary fuel source (i.e., more then fifty percent of the full energy requirement) other then oil, natural gas, a product of oil or natural gas, or coal.

For a farmer considering the purchase of an ethanol production unit of this small capacity, his paramount concern should be the availability of labor for ethanol production. If sufficient labor is convenient, he should bear in mind that even under the more favorable condition depicted in this model, the magnitude of the yearly cash flows will not allow the purchase of much more then a hobby still. Then the potential ethanol producer must assure himself of a market for the lower proof ethanol or being willing to pay a considerable premium for using it in his own machinery.

5.4.2 Implications for the Farmer Considering Large Scale Ethanol Production

To install a 100,000 gallon unit is a more critical decision since the investment expenditure would be considerably higher. Basically, however, the implications of the model results for the farmer considering this larger scale unit are similar to those made for the smaller scale unit. Labor requirements again surface as a primary concern but in this case the issue might more aptly be viewed as being able to install the requisite labor saving technology for a cost under the annual cash flows indicated by the model.

The plant investment as a function of annual production for the unit purchased at 10 percent interest in this model is $1.50 ± .30 per annual gallon. A recently released study by Raphael Katzen Associates International, Inc. entitled "Farm and Cooperative Alcohol Plant Study" reported the actual plant investment for a 100,000 gallon per year unit would be closer to $4.88 per annual gallon.[2/] This cost represents the investment in every aspect of the plant. If the farmer is able to supply such items as storage, building, etc. from his existing infrastructure the cost per annual gallon will drop considerably. In fact, it will very likely be

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[2/] Katzen Associates International, 1980.

the farmers ability or inability to supply part of the plant either from what he already has in place or can construct himself, that will be the deciding factor in the 100,000 gallon capacity venture.

5.4.3 Technological Considerations

A number of technological trade-offs present themself to the farmer considering ethanol production. For instance, depending on the labor constraint he is working under, the farmer may choose to spend more on a larger column with no automation operating it for only the time when supervision is available each day. This would afford him a better opportunity to expand should a shifting economic environment warrant. On the other hand, he could opt for a smaller column which would operate continuously to process a desired volume of ethanol. In this case the money saved by buying the smaller distillation column could be spent on automating the operation. There is little freedom for expanding the capacity of this smaller unit but when labor is a constraining factor, labor-free operation becomes the chief concern.

Most of the labor and energy saving technology applicable to ethanol production is extremely sensitive to economies of scale. There is little, if any, difference between the microprocessor used to operate a 20 gallon per hour production unit and that used to monitor the functions of a 50 gallon per hour flow rate. Still, much of the equipment used in small scale production units currently being developed are fabricated specifically for use in these prototype models. If a market develops sufficient to justify mass production of standardized small ethanol production units, some improvement in the economics of small scale ethanol production could be expected. Yet in the context of the existing environment, ethanol production on either of the scales chosen in this study appears to be a highly dubious endeavor.

5.5 Policy Implications

The first very real question policy makers must address is whether or not it is in society's best interest to promote on farm ethanol production. Two reasons for doing so might be to insure the security of domestic food production against an erruption in liquid fuel supplies or as a means of bolstering domestic fuel supplies.

In the existing environment, a disruption so devastating as to deprive the United States of enough petroleum to continue food production seems highly unlikely particularly since about 50 percent of the U.S. petroleum needs come from internal sources. Policy makers would do better to concentrate on developing a viable rationing plan which would insure agriculture adequate supplies of domestic fuel should foreign supplies suddenly be cut off or diminished. Any legislation concerning farm production and use of ethanol should be geared toward research and development. At present, technology for retro-fitting farm vehicles is scarce and unproven, to say the least. Until farmers can rest assured the costly renovations needed to install an ethanol-run tractor fleet and/or ethanol production unit is justified, little change over can be expected. In orienting policy incentive toward research and development, the dissemination of information can not be overlooked or underemphasized.

Already a great deal has been done to enhance the economics of ethanol production under the pretense of replacing U.S. pretroleum needs with renewable alcohol. Federal tax incentives include a thirty cent tax credit per gallon of 150 to 190 proof alcohol produced, a forty cent tax credit per gallon of over 190 proof alcohol produced, and a ten percent tax credit for the purchase of "alternative energy property." Furthermore, $525 million has been earmarked for loans, loan guarantees, price guarantees, and purchase agreements from the Department of Agriculture (USDA) for plants that will produce biomass derived alcohol fuels, generally with annual production capacities less than 15 million gallons. Even so, farm scale ethanol production realizes few of the benefits. Part of the problem is that, like the current technology, these incentives are sensitive to economies of scale. The cost of fulfilling requirements for a guaranteed loan application is practically the same rather you are building a still with a yearly capacity of 100,000 gallons or one producing 1 million gallons annually.

If indeed the answer to the question posed at the beginning of the policy discussion is "yes, we should promote on-farm ethanol production," then an effort is needed to specifically aim the current legislation at the farmer. Also, the provision of a supporting infrastructure would need to be advanced. Central "topping plants" which would buy lower proof alcohol for further processing to anhydrous alcohol may need institutional support to become viable. The continuing research into the effects of intensive energy cropping programs on long term soil fertility is essential as is the careful evaluation of the broad range effects of any new policy.

All in all, it appears that on-farm ethanol production is a practice that has not yet come of age, if indeed it ever will. In the interim, a prerequisite to the success of any future program is the research which would develop an ethanol production unit that requires the minimum of the farmers time so that he might continue the pursuit of the enterprise in which he holds a comparative advantage; that is, the provision of the nation's nutrition.

5.6 Limitations of the Research

Probably the most apparent problem with adopting the linear programming (LP) approach used in this research has been its static nature. Although helpful when comparing equilibrium situations, static models offer little opportunity to evaluate decision making alternatives in a dynamic world. There are those who would argue that with today's rapidly changing inflation rate, interest rates and energy prices, there is hardly, if ever, enough time between shifts to allow an equilibrium state to be attained, further depreciating the adequacy of a static model. An attempt at making LP models more dynamic can be found in the Appendix C.

At any rate, under its present design, the model still only yields partial equilibrium solutions when conducting sensitivity analysis. It is not realistic to assume that while varying the cost of one factor the rest of the prices remain constant. This ignores the interdependence encountered in dealing with agricultural products that exhibit numerous competitive, complimentary, and supplementary relationships. However, the model may be useful when examining the effects encountered when one factor's price is rising more rapidly relative to the others (i.e., energy prices). Just the same, it cannot be expected that all factors would be affected equally by rising energy prices. Selling dried corn would definitely experience different pressures then would the sell of soybeans, for example. Such partial equilibrium analysis is representative of a very short run phenomenon which warrants guarded credence in this dynamic world.

In spite of these deficiencies, the approach remains sufficient for determining the immediate feasibility of on-farm production particularly since there is little indication where future technology in the field might lead. Indeed, the acquisition of reliable information as to the nature of the current technology in small scale ethanol production proved to be a troublesome concern. This inability to obtain concurring reports on the performance of small distillation units was a hindrance in one respect but it necessitated designing the model to easily accommodate new and changing data. The information used here was at least from substantiated sources if not the result of first hand observation.

5.7 Additional Needed Research

With the aforementioned inadequacies in mind, it is evident that subsequent studies should deal more fully with the problem in the dynamic sense. Likewise it would be interesting to conduct sensitivity analysis in a state of general equilibrium, notably to fully account for the effects induced by changing energy prices and to ascertain more clearly the true value of the byproduct.

The model is intended for easy adaption of any variety of energy innovations. It follows, since energy considerations are becoming increasingly important, that all new concepts should be weighed one against another and in conjunction with each other. The further development of this model could conveniently depict a farming system designed to evaluate all existing energy subsystems.

5.8 Ending Statement

It would not be fair to conclude on the relatively negative notes listed in the last two sections of this chapter without some mention of one very positive aspect of the research. In building a model of a whole farm system the need for collaboration of several disciplines immediately emerged. Such a multidisciplinary approach would have been impossible without the unselfish attention of otherwise unrelated individuals. But should that cooperation be lacking, the entire research would have been rendered up to nothing more than an intellectual exercise. Without a doubt, it will be this type of collective effort which will continue to legitamize inquisitive research.

APPENDICES

APPENDIX A

DATA AND CALCULATIONS USED IN CONSTRUCTING THE WHOLE FARM LINEAR PROGRAMMING MODEL

A.1 Corn Grain Yield

Corn grain yields were entered into the model as pounds of dry matter. Doing so made it easy to formulate rations for cattle feeding and meet the feedstock demands for ethanol production. Still, hauling cost had to be figured using yield on a wet basis. Tables A-1 and A-2 list the assumption and results of the calculations.

TABLE A-1. Corn Yields at 15.5% Moisture on a Wet Basis[1/]

Activity[2/]	Yield (bu/acre @ 15.5% moisture)	% Moisture at Harvest	Wet Yield (bu/acre)
S_1F_3	110.0	30	132.8
S_1F_4	107.8	26	123.1
S_1F_5	102.3	22	110.8
S_2F_4	106.7	28	125.2
S_2F_5	102.3	24	113.7
S_3F_4	99.0	32	123.0
S_3F_5	93.5	26	106.8

[1/]A bushel of corn is defined as 56 lbs. of corn.

[2/]S_iF_j depicts corn planted in the i^{th} spring period and harvest in the j^{th} fall period.

TABLE A-2. Corn Yield on a Dry Matter Basis[1/]

Activity[2/]	Wet Yield (lbs/acre)	% Dry Matter at Harvest	Dry Matter Yield (lbs/acre)
S_1F_3	7,436.2	70	5,205.4
S_1F_4	6,893.2	74	5,101.3
S_1F_5	6,206.5	78	4,841.1
S_2F_4	7,012.3	72	5,048.9
S_2F_5	6,369.4	76	4,840.8
S_3F_4	6,889.1	68	4,684.5
S_3F_4	5,979.0	74	4,424.4

[1/] Dry matter basis is moisture free basis.

[2/] S_iF_j depicts corn planted in the j^{th} spring period and harvest in the j^{th} fall period.

A.2 Corn Silage Yield

Corn silage, like corn grain, was entered in the model as pounds per acre on a dry matter basis. This allows ease of movement of silage from growing activities to cattle feeding activities. Cattle rations are calculated on a dry matter basis. Table A-3 lists yields on both a wet basis for calculating hauling cost and a dry matter basis.

TABLE A-3. Corn Silage Yields

Activity[1/]	Yield @ 32% Dry Matter (ton/acre)	Wet Yield (lbs/acre)	Dry Matter Yield (lbs/acre)
S_1F_1	16.5	33,000	10,560
S_1F_2	17.0	34,000	10,880
S_2F_1	16.0	32,000	10,240
S_2F_2	16.5	33,000	10,560
S_3F_1	15.5	31,000	9,920
S_3F_2	16.0	32,000	10,240

[1/] S_iF_j depicts corn planted in the i^{th} spring period and harvested as silage in the j^{th} fall period.

A.3 Annual Use Cost of Machinery Compliment

The cropping subsystem consisted of 750 acres on which corn and/or corn silage and soybeans could be grown. Machinery cost were calculated outside the model using an agricultural engineering model developed by Fran Wolak. Fuel cost, which were included in the machinery cost calculated by the Wolak model at $.75 per gallon, were subtracted out because they were enter in the whole farm LP in order to be more realistic in depicting rising fuel costs.

The annual use cost per acre of the machinery compliment as calculated by the Wolak model are:

All corn grain	- $71.26
1/2 corn grain, 1/2 corn silage	- $71.00
All corn silage	- $77.00

Fuel consumption and cost for carrying out all of the related operations are:[1/]

	Fuel Consumption (gal/acre)	Cost ($.75/gal)
Soybean operations	8.14	$6.105
Corn grain operations	8.43	$6.323
Corn silage operations	10.23	$7.673

Annual use cost of the machinery compliment minus the fuel costs are:

All corn grain = 71.26-[(.8 x corn fuel cost) + (.2 x soybean fuel cost)]
= $64.98/acre

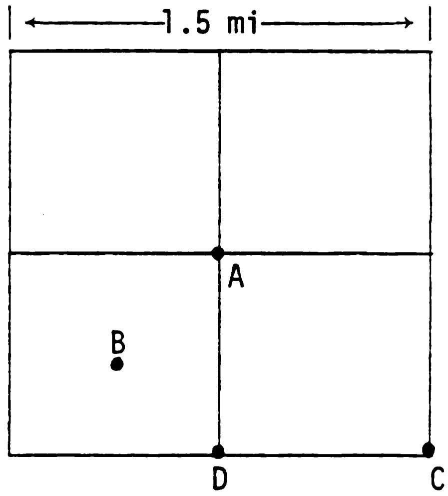
1/2 corn grain, 1/2 corn silage = 71.0-[(.4 x corn fuel cost) + (.4 x silage fuel cost) + (.2 x soybean fuel cost)
= $64.18/acre

All corn silage = 77.0-[(.8 x silage fuel cost) + (.2 x soybean fuel cost)
= $69.64/acre

[1/] White, Robert G., "Fuel Requirements for Selected Farming Operations," Etension Bulletin E-780, February, 1974.

A.4 Average Distance Traveled from Field to Storage

In order to access the cost of hauling the harvested crops to storage, an average process was designed to find an average distance traveled to and from storage. It is assumed that the 750 acres is located in a 1 1/2 mile square (72% tillable). The square is divided into quarters and average distances is taken to the center of the four quarters and the center of the large square from four points (A, B, C, and D). These distances are totaled and averaged. All routes are considered to make right angled turns.



A	1.5 + 1.5 + 1.5 + 1.5	=	6.0
B	1.5 + 1.5 + 1.5 + 3.0	=	7.5
C	3.0 + 3.0 + 1.5 + 3.0 + 4.5	=	15.0
D	1.5 + 1.5 + 1.5 + 3.0 + 3.0	=	10.5
	39 ÷ 18 trips = 2.16 mi	=	39.0

By this averaging process, an average of 2.16 miles, both ways is determined for field to storage trips. This distance is then used to calculate the fuel use for hauling the harvested grain and silage.

A.5 Total Fuel Use for Field Activities

The amount of fuel used to move the produce from field to storage is affected by the amount to be moved or in other words, yield per acre. Therefore, total fuel cost for each cropping activity is calculated. The results are in Table A-4.

TABLE A-4. Fuel Use for All Field Activities

Activity	Hauling Fuel Use (gal/acre)	Total Fuel Use (gal/acre)
Corn Grain		
S_1F_3	.72	9.15
S_1F_4	.66	9.09
S_1F_5	.60	9.03
S_2F_4	.67	3.10
S_2F_5	.61	9.04
S_3F_4	.66	9.09
S_3F_5	.57	9.00
Soybeans		
S_3F_2	.20	8.34
S_3F_3	.19	8.33
S_4F_2	.20	8.34
S_4F_3	.19	8.33
S_5F_4	.14	8.28
Corn Silage		
S_1F_1	3.04	13.27
S_1F_2	3.13	13.36
S_2F_1	2.95	13.18
S_2F_2	3.04	13.27
S_3F_1	2.85	13.08
S_3F_2	2.95	13.18

A.6 Determining Feed Disappearance on a Dry Matter Basis

Determining the total feed disappearance in pounds of dry matter for each of the rations available to be fed is a three step process. The steps are defined and described as follows:

Step 1. Determine the total number of days required to feed an animal from 450# to market weight.

To initiate the process of determining feed disappearance suitable feeding periods are chosen and the number of days in each period is calculated. The periods are defined as:

period 1 - 450 - 600 lbs

period 2 - 600 - 800 lbs

period 3 - 800 - 1050 lbs

For period one and two there is a constant daily weight gain determined by the energy level of the ration. In period three the daily gain decreased and dry matter intake increased as the body weight went from 800 to 1050 lbs. Furthermore, a two week adjustment peiod is added to the first period when it is assumed that dry matter intake is 90 percent of normal and there is not weight gain. This is the generally accepted length of time needed to bring the calves on feed and allow them to adjust to the new environment. Accordingly, the days in period one are the total weight gained in the period divided by the constant daily gain plus two weeks. The days in period two are calculated by dividing the total weight gained by the constant daily gain. In period three, the days are figured at fifty pound intervals since the daily gain is changing. A .5 percent shrinkage during marketing is assumed so the animal is actually feed to 1055.25 pounds (1050 + .5%).

The head per year is 330 divided by the total days needed to feed the animal from 450 lbs to market weight. A year 330 days total is chosen to take account of operation below capacity during turn over and maintenance. This figures assumes a 90 percent of capacity level of operation.

Step 2. Determining weighted average daily feed consumption in pounds of dry matter.

Each ration reports an increase in dry matter intake at 50 pound intervals in weight gain. In order to get an average daily consumption during each feeding period, it is necessary to calculate a weighted average over the length of each period. This is accomplished by multiplying the average daily intake at each 50 pound interval by the ratio of the days the animal is at that weight to the total days in the period. The products are then added together to get the weighted average daily feed consumption.

Step 3. Determining to total yearly feed disappearance in pound of dry matter.

The total feed disappearance per period in pounds of dry matter is the days in each period times the weighted average consumption per day for the relevant period. Summing these products gives the total feed disappearance for one feeder cow from 450 pounds to market weight. Multiplying this total by the number of head produced per year gives the total feed disappearance in pounds of dry matter per feedlot place in one year.

Tables A-5, A-6, and A-7 follow the three steps calculating through for each ration of three different energy intake levels. The two-phase ration is a combination of the 44 Mcal NE_g/lb ration fed in the first two periods and the 63 Mcal NE_g/lb ration fed in the finishing or third period.

TABLE A-5 Feed Disappearance for 44 Mcal NE_g/lb Ration

Step 1. Determining the number of days required to feed one animal from 450# to market weight.

Days in period 1	= (600 - 450)/1.825 + 14	=	96.192
Days in period 2	= (800 - 600)/1.825	=	109.589
Days in period 3	= (850 - 800)/1.769	=	28.265
	(900 - 850)/1.713	=	29.189
	(950 - 900)/1.657	=	30.175
	(1000 - 950)/1.572	=	31.807
	(1050 - 1000)/1.487	=	33.625
			153.061
	(1050 x .005)/1.487	=	3.531
	Total	=	362.373
	Head/year	=	330/362.4 = .911

Step 2. Determining weighted average daily feed consumption

Period 1 $(11.913 \times 9 \times \frac{14}{96.192}) + (11.913 \times \frac{20.55}{96.192}) + (12.893 \times \frac{20.55}{96.192}) + (13.868 \times \frac{20.55}{96.192}) + (14.782 \times \frac{20.55}{96.192}) = 12.975$

Period 2 $14.782 + 15.697 + 16.594 + 17.475 + 18.342/5 = 16.578$

Period 3 $18.342 + (18.875 \times \frac{28.26}{153.06} \times 5) + (19.367 \times \frac{29.19}{153.06} \times 5) + (19.820 \times \frac{30.18}{153.06} \times 5) + (20.057 \times \frac{31.81}{153.06} \times 5) + (20.242 \times \frac{33.62}{153.06} \times 5)/6 = 19.475$

Step 3. Determining total feed disappearance in pounds of dry matter

Period 1	96.192 x 12.975	= 1248.09
Period 2	109.589 x 16.578	= 1816.76
Period 3	156.592 x 19.475	= 3049.63
		6114.48 lbs/animal
	x .911	= 5570.29 lbs/year

TABLE A-6. Feed Disappearance for 53 Mcal NE_g/lb Ration

<u>Step 1</u>. Determining the number of days required to feed one animal from 450# to market weight

Days in period 1 =	(600 - 450)/2.402 + 14	= 76.448
Days in period 2 =	(800 - 600)/2.402	= 83.264
Days in period 3 =	(850 - 800)/2.338	= 21.386
	(900 - 850)/2.274	= 21.988
	(950 - 900)/2.21	= 22.624
	(1000 - 950)/2.113	= 23.663
	(1000 - 1000)/2.015	= 24.814
		114.475
	(1050 x .005)/2.015	= 2.605
	Total	= 276.792
	Head/year	= 330/276.792 = 1.192

<u>Step 2</u>. Determining weighted average daily feed consumption

Period 1 $(11.913 \times 9 \times \frac{14}{76.448}) + (11.913 \times \frac{15.612}{76.448}) + (12.893 \times \frac{15.612}{76.448})$

$+ (13.848 \times \frac{15.612}{76.448}) + (14.782 \times \frac{15.612}{76.448}) = 12.876$

Period 2 $14.782 + 15.897 + 16.594 + 17.475 + 18.342/5 = 16.578$

Period 3 $18.342 + (18.875 \times \frac{21.386}{114.475} \times 5) + (19.367 \times \frac{21.988}{114.475} \times 5) +$

$(19.820 \times \frac{22.624}{114.475} \times 5) + (20.057 \times \frac{23.663}{114.475} \times 5) + (20.242 \times$

$\frac{24.814}{114.475} \times 5)/6 = 19.471$

<u>Step 3</u>. Determining total feed disappearance in pounds of dry matter

Period 1	76.448 x 12.876 =	984.344
Period 2	83.264 x 16.578 =	1380.351
Period 3	114.475 x 19.471 =	<u>2279.665</u>
		4644.360 lbs/animal
	x 1.192 =	5536.08 lbs/year

TABLE A-7. Feed Disappearance from 63 Mcal NE_g/lb Ration

<u>Step 1</u>. Determining the number of days required to feed one animal from 450# to market weight

Days in period 1 =	(600 - 450)/2.699 + 14	=	69.576
Days in period 2 =	(800 - 600)/2.699	=	74.101
Days in period 3 =	(850 - 800)/2.632	=	18.997
	(900 - 850)/2.565	=	19.493
	(950 - 900)/2.497	=	20.024
	(1000 - 950)/2.396	=	20.868
	(1050 - 1000)/2.293	=	21.805
			101.187
	(1050 x .005)/2.293	=	2.270
	Total	=	274.154
	Head/year	=	330/247.2 = 1.335

<u>Step 2</u>. Determining weighted average daily feed consumption

Period 1 $(10.81 \times 9 \times \frac{14}{69.576}) + (10.81 \times \frac{13.894}{69.576}) + (11.699 \times \frac{13.894}{69.576})$

$+ (12.566 \times \frac{13.894}{69.576}) + (13.414 \times \frac{13.894}{69.576}) = 11.641$

Period 2 $13.414 + 14.244 + 15.058 + 15.857 + 16.644/5 = 15.043$

Period 3 $16.644 + (17.127 \times \frac{18.997}{101.187} \times 5) + (17.574 \times \frac{19.493}{101.187} \times 5) +$

$(17.985 \times \frac{20.024}{101.187} \times 5) + (18.2 \times \frac{20.868}{101.187} \times 5) + (18.368 \times$

$\frac{21.805}{101.187} \times 5)/6 = 17.667$

<u>Step 3</u>. Determining Total Feed Disappearance in pounds of dry matter

Period 1	69.576 x 11.641	=	809.93
Period 2	74.101 x 15.043	=	1114.70
Period 3	103.477 x 17.667	=	<u>1828.13</u>
			3752.76 lbs/animal
	x 1.335	=	5009.935 lbs/year

A.7 Feed and Manure Handling Time Requirements

Feed handling time is a function of the total volume of feed to be handled. Therefore, pounds of dry matter for each feed component listed in Table 3-20 in Chapter III must be converted to "As Is" pounds of feed to be fed. This is accomplished by dividing the pounds of dry matter by the percent dry matter for each feed ingredient. The results are listed in Table A-8.

Time required for feeding in each period is based on the total pounds of feed fed times .0001. Woody and Black (1978) propose using .0001 hours per pound of feed fed as an approximation of feeding time. The number of hours per year required for feeding is the total "As Is" pounds of feed times .0001. Time per day is the hours per year divided by 365. Remember that the feeding time is on a per head basis so that it takes 4 hours a day to feed 1000 head of cattle if it takes .004 hours to feed 1. The hour per period is the hours per day times the number of days in the period. Many of the spring and fall periods have the same number of days and are reported in the same column (i.e., S_1, S_2, S_3 and S_4 all have 10 days and are all represented in the fourth column of Table A-9). Results are in Table A-9.

The ration energy concentration affects the quantity of manure an animal will excrete and the quantity of manure, in turn, has an influence on its handling time. As the percent grain in the ration dry matter decreases, the total volume of manure produced increases because of the lower digestibility of roughages. As in feed handling, this fact favors the high energy rations by a lower nonfeed cost per animal fed. Labor requirements for manure handling are (in hours per head capacity per year)

TABLE A-8. Total "As Is" Pounds Fed Per Year (330 Days) for One Feedlot Space

Ration	Corn (72)[1/]	Soybean Meal (90)	DDGS (7)	Corn Silage (22)	Total
1%; 53 Mcal NE_g/lb	Total DM - 5536.08 lbs.				
Soybean + Urea	2,917.4	86.0		10,290.3	13,359.6
Soybean - Urea	2,651.3	337.9		10,290.3	13,312.9
DDGS + Urea	2,847.8		1,894.1	10,959.8	15,768.7
DDGS - Urea	2,155.1		10,028.3	10,191.2	22,399.2
Two Phase	Total DM - 5,200.81 lbs.				
Soybean + Urea	2,281.2	21.8		10,959.8	13,326.2
Soybean - Urea	2,281.2	358.4		10,459.0	13,125.9
DDGS + Urea	2,281.2		373.6	10,939.3	13,662.8
DDGS - Urea	2,281.2		6,213.3	9,794.8	18,309.6
44 Mcal NE_g/lb	Total DM - 5,570.29 lbs.				
Soybean + Urea		37.1		17,058.28	17,173.4
Soybean - Urea		408.5		16,205.38	16,630.1
DDGS + Urea			636.6	17,023.44	17,738.0
DDGS - Urea			10,583.0	15,073.94	25,662.5
63 Mcal NE_g/lg	Total DM - 5,009.935 lbs.				
Urea added	5,925.4			2,063.34	8,071.1
Soybean - Urea	5,689.0	220.7		2,071.38	8,032.0
DDGS - Urea	5,366.6		6,534.1	2,004.19	13,953.7

[1/] Number in parenthesis is percent dry matter.

TABLE A-9. Time Required for Feeding (.0001 hr/lb)[1/]

Ration	Hr/yr	Hr/day	Hr/period: Dec. 2- Apr. 19	S_1, S_2 S_3, S_4	S_5, S_6 S_7	July 2 Aug. 3	F_1, F_3 F_4	F_2, F_5 F_6
1%; 53 Mcal NE_g/lb								
Soybean + Urea	1.339	.004	.509	.037	.04	.220	.055	.059
Soybean - Urea	1.331	.004	.507	.036	.04	.219	.055	.058
DDGS + Urea	1.577	.005	.601	.043	.048	.259	.065	.069
DDGS - Urea	2.240	.007	.853	.061	.068	.368	.092	.098
Two Phase								
Soybean + Urea	1.333	.004	.507	.036	.04	.219	.055	.058
Soybean - Urea	1.313	.004	.500	.036	.04	.216	.054	.058
DDGS + Urea	1.366	.004	.520	.037	.041	.225	.056	.060
DDGS - Urea	1.831	.006	.697	.050	.055	.301	.075	.080
44 Mcal NE_g/lb								
Soybean + Urea	1.717	.005	.654	.047	.052	.282	.071	.075
Soybean - Urea	1.663	.005	.633	.046	.05	.273	.068	.073
DDGS + Urea	1.774	.005	.676	.049	.053	.292	.073	.078
DDGS - Urea	2.566	.008	.977	.07	.077	.422	.105	.112
63 Mcal NE_g/lb								
Urea added	.807	.002	.307	.022	.024	.133	.033	.035
Soybean - Urea	.803	.002	.305	.022	.024	.132	.033	.035
DDGS - Urea	1.395	.004	.531	.038	.042	.229	.057	.061

[1/]Influence of Ration Grain Content on cost of feeding, Manure Handling and Storage and Manure Credit, Woody, H. D., and Black, J. R., Research Report 353, 1978.

.429, .579 and .679 for the .44 Mcal NE_g/lb 1% and two-phase and 63 Mcal NE_g/lb rations, respectively. These requirements are distributed equally over the whole year and are listed in Table A-10. Time for general maintenance such as sorting, veternarian work, etc., is also listed based on an assumption of one hour a day for a 750 head herd during a 365 day year.

Table A-11 merely sums the feeding manure handling, and maintenance time requirements and lists them as they appeared in the model.

TABLE A-10. Time Required for Manure Handling

Ration	Hr/period							
	hr/ yr	hr/ day	Dec. 2- Apr. 19	S_1, S_2, S_3, S_4	S_5, S_6, S_7	July 2- Aug. 30	F_1, F_3, F_4	F_2, F_5, F_6
1% & Two Phase	.579	.002	.221	.016	.017	.095	.024	.025
44 Mcal/lb NE_g	.679	.002	.259	.019	.020	.112	.028	.030
63 Mcal/lb NE_g	.429	.001	.163	.012	.013	.071	.018	.019
General Maintenance[1/]	.486	.0013	.185	.013	.015	.08	.02	.021

[1/]Based on an assumption of one hour a day for a 750 head herd during a 365 day year.

TABLE A-11. Total Time Required per Period for the Feeding, Handling Manure, and General Maintenance of One Feedlot Space

Ration	Dec. 2-Apr. 19	S_1, S_2, S_3, S_4	S_5, S_6, S_7	July 2-Aug. 30	F_1, F_3, F_4	F_2, F_5, F_6
1%; 53 Mcal NE_g/lb						
Soybean + Urea	.915	.066	.072	.395	.094	.105
Soybean - Urea	.913	.065	.072	.394	.099	.104
DDGS + Urea	1.007	.072	.08	.434	.104	.115
DDGS - Urea	1.259	.09	.10	.543	.136	.144
Two Phase						
Soybean + Urea	.913	.065	.072	.394	.099	.104
Soybean - Urea	.906	.065	.072	.391	.098	.104
DDGS + Urea	.926	.066	.073	.400	.100	.106
DDGS - Urea	1.103	.079	.087	.476	.119	.126
44 Mcal NE_g/lb						
Soybean + Urea	1.098	.079	.087	.474	.119	.126
Soybean - Urea	1.077	.078	.085	.465	.116	.124
DDGS + Urea	1.12	.081	.088	.484	.121	.129
DDGS - Urea	1.421	.102	.112	.614	.153	.163
63 Mcal NE_g/lb						
Urea added	.655	.047	.052	.284	.061	.075
Soybean - Urea	.653	.047	.052	.283	.061	.075
DDGS - Urea	.879	.063	.070	.380	.085	.101

A.8 The Full Time Labor Coefficients

The full time labor supply and time cost coefficients are based on a 250 day working year. This is done to take account of weekends and eleven holidays or vacation days. A day was considered to be 10 hours long. An annual salary of $13,000 is assumed and the time supplied was spread evenly over each period throughout the year. Part time labor was hired on an hourly basis with an efficiency of 859.

$$250 \text{ days} \times 10 \text{ hrs/day} = 2{,}500 \text{ hrs/year}$$

$$2500 \text{ hrs/year} \div 365 \text{ days/year} = 6.849 \text{ hrs/day}$$

TABLE A-12. Full Time Labor Coefficients

Period	Day/ Period	Weather Constraint	Hrs/ Period	Labor in Excess of Weather Constraint
S_1	10	79.2	68.5	
S_2	10	90.0	68.5	
S_3	10	4.0	68.5	
S_4	10	119.7	9.0	
S_5	11	138.6	75.3	
S_6	11	138.6	75.3	
S_7	11	138.6	75.3	
July 2 - Aug. 30	60			
F_1	15	105.	102.7	
F_2	16	105.4	109.9	4.5
F_3	15	79.5	102.7	23.2
F_4	15	53.6	102.7	49.2
F_5	16	37.2	109.9	72.3
F_6	16	22.4	109.9	87.5
Dec. 2 - April 19	139		952.1	
	365 days		2500.00 hours	

A.9 Fixed and Variable Costs for Cattle Feeding

The fixed costs is the capital and interest cost for slated floor enclosement allowing 16 square feet of space per animal. This and the variable costs are listed in Table A-13. The annual cost per feedlot space differ for each ration because the rate of gain differs with each ration. Therefore variable cost is multiplied by the appropriate factor. The remainder of the table is self explanatory.

TABLE A-13. Fixed and Variable Costs for Feeding Feedlot Steers (Cost/Feedlot Space)

Fixed Cost			
feedlot space			
16^2 feet, slated floors			\$300 for 15 years
			.06/day \$20/year
Interest 10%			\$15/year
Variable Costs			
Death Loss	2% on calves	.02 x 4.50 cwt x \$95 = 8.55	
	1% on yearlings	.01 x 10.5 cwt x \$72 = 7.56	
		Total/Head 16.11	
		1% x 1.192 hd/yr	= 19.20
		Two phase x 1.067	= 17.19
		44 x .911 hd/yr	= 14.68
		63 x 1.335 hd/yr	= 21.51
	remenson - .01 day		= 3.30/year
	Ralgro (implant) 4.50/head		
		1% x 1.192 hd/yr	= 5.36
		Two phase x 1.067	= 4.80
		44 x .911 hd/yr	= 4.10
		63 x 1.335 hd/yr	= 6.01
	salt 12 lb/year @ .05/lb		= .60
	process into feedlot @ 4.40/head		
		1% x 1.192 hd/yr	= 5.24
		Two phase x 1.067	= 4.69
		44 x .911 hd/yr	= 4.01
		63 x 1.335 hd/yr	= 5.87

TABLE A-13 (Continued)

Transport in; 1000 miles 18.80/head		
	1% x 1.192 hd/yr	= 22.41
	Two phase x 1.067	= 20.06
	44 x .911 hd/yr	= 17.13
	63 x 1.335 hd/yr	= 25.10
Marketing and Transport 1.75/local mile/42,000 lbs based on 100 mile marketing		
	1% x 1.192 hd/yr	= 5.22
	Two phase x 1.067	= 4.67
	44 x .911 hd/yr	= 3.99
	63 x 1.335 hd/yr	= 5.84
Vet Medicine 5.00/head		
	1% x 1.192 hd/yr	= 5.96
	Two phase x 1.067	= 5.34
	44 x .911 hd/yr	= 4.56
	63 x 1.335 hd/yr	= 6.68
Vitamins and Minerals 120 lbs @ .15/head		
	1% x 1.192 hd/yr	= 21.46
	Two phase x 1.067	= 19.21
	44 x .911 hd/yr	= 16.40
	63 x 1.335 hd/yr	= 24.03
Sub Total	1%	= 88.75
	Two phase	= 79.86
	44	= 68.77
	63	= 98.98
Interest on working capital 14% for 6 months		
	1%	= 6.21
	Two phase	= 5.59
	44	= 4.81
	63	= 6.93
TOTAL		
	1%	= 94.96
	Two phase	= 85.45
	44	= 73.58
	63	=105.91

APPENDIX B

ACTIVITIES AND CONSTRAINTS AS THEY WERE ORDERED IN THE WHOLE FARM LINEAR PROGRAMMING MODEL

Activities in the Model (243)

1. Rent Land
2. Rent Out Land
3. Hire Labor 12/2-4/14
4. Hire Labor S_1
5. Hire Labor S_2
6. Hire Labor S_3
7. Hire Labor S_4
8. Hire Labor S_5
9. Hire Labor S_6
10. Hire Labor 7/2-8/30
11. Hire Labor F_1
12. Hire Labor F_2
13. Hire Labor F_3
14. Hire Labor F_4
15. Hire Labor F_5
16. Hire Labor F_6
17. Hire Full-Time Labor
18. Plant Corn S_1 Harvest F_3
19. Plant Corn S_1 Harvest F_4
20. Plant Corn S_1 Harvest F_5
21. Plant Corn S_2 Harvest F_4
22. Plant Corn S_2 Harvest F_5
23. Plant Corn S_3 Harvest F_4
24. Plant Corn S_3 Harvest F_5
25. Transfer Harvest F_3 to Disc F_4
26. Transfer Harvest F_3 to Disc F_5
27. Transfer Harvest F_3 to Disc F_6
28. Transfer Harvest F_4 to Disc F_4
29. Transfer Harvest F_4 to Disc F_5
30. Transfer Harvest F_4 to Disc F_6
31. Transfer Harvest F_5 to Disc F_5
32. Transfer Harvest F_5 to Disc F_6
33. Disc F_4
34. Disc F_5
35. Disc F_6
36. Transfer Disc F_4 to Plow F_4
37. Transfer Disc F_4 to Plow F_5
38. Transfer Disc F_4 to Plow F_6
39. Transfer Disc F_4 to Plow S_1
40. Transfer Disc F_4 to Plow S_2
41. Transfer Disc F_5 to Plow F_5

42. Transfer Disc F_5 to Plow F_6
43. Transfer Disc F_5 to Plow S_1
44. Transfer Disc F_5 to Plow S_2
45. Transfer Disc F_6 to Plow F_6
46. Transfer Disc F_6 to Plow S_1
47. Transfer Disc F_6 to Plow S_2
48. Plow F_4
49. Plow F_5
50. Plow F_6
51. Plow S_1
52. Plow S_2
53. Transfer Plow F_4 to SBP S_1*
54. Transfer Plow F_4 to SBP S_2
55. Transfer Plow F_5 to SBP S_1
56. Transfer Plow F_5 to SBP S_2
57. Transfer Plow F_6 to SBP S_1
58. Transfer Plow F_6 to SBP S_2
59. Transfer Plow S_1 to SBP S_1
60. Transfer Plow S_1 to SBP S_2
61. Transfer Plow S_2 to SBP S_2
62. Seed Bed Preparation S_1
63. Seed Bed Preparation S_2
64. Transfer SBP S_1 to Plant S_1
65. Transfer SBP S_1 to Plant S_2
66. Transfer SBP S_1 to Plant S_3
67. Transfer SBP S_1 to Plant S_4
68. Transfer SBP S_1 to Plant S_5
69. Transfer SBP S_2 to Plant S_2
70. Transfer SBP S_2 to Plant S_3
71. Transfer SBP S_2 to Plant S_4
72. Transfer SBP S_2 to Plant S_5
73. Plant Corn Silage S_1 Harvest F_1
74. Plant Corn Silage S_1 Harvest F_2
75. Plant Corn Silage S_2 Harvest F_1
76. Plant Corn Silage S_2 Harvest F_2
77. Plant Corn Silage S_3 Harvest F_1
78. Plant Corn Silage S_3 Harvest F_2
79. Plant 128 Day Soybeans S_3 Harvest F_2
80. Plant 128 Day Soybeans S_3 Harvest F_3
81. Plant 117 Day Soybeans S_4 Harvest F_2
82. Plant 128 Day Soybeans S_4 Harvest F_3
83. Plant 128 Day Soybeans S_5 Harvest F_4
84. Transfer Harvest F_1 to Fertilize F_4
85. Transfer Harvest F_1 to Fertilize F_5

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*SBP - Seed Bed Preparation.

86. Transfer Harvest F_1 to Fertilize F_6
87. Transfer Harvest F_2 to Fertilize F_4
88. Transfer Harvest F_2 to Fertilize F_5
89. Transfer Harvest F_2 to Fertilize F_6
90. Transfer Harvest F_3 to Fertilize F_4
91. Transfer Harvest F_3 to Fertilize F_5
92. Transfer Harvest F_3 to Fertilize F_6
93. Transfer Harvest F_4 to Fertilize F_4
94. Transfer Harvest F_4 to Fertilize F_5
95. Transfer Harvest F_4 to Fertilize F_6
96. Fertilize F_4
97. Fertilize F_5
98. Fertilize F_6
99. Transfer Fertilize F_4 to Plow F_4
100. Transfer Fertilize F_4 to Plow F_5
101. Transfer Fertilize F_4 to Plow F_6
102. Transfer Fertilize F_4 to Plow S_1
103. Transfer Fertilize F_4 to Plow S_2
104. Transfer Fertilize F_5 to Plow F_5
105. Transfer Fertilize F_5 to Plow F_6
106. Transfer Fertilize F_5 to Plow S_1
107. Transfer Fertilize F_5 to Plow S_2
108. Transfer Fertilize F_6 to Plow F_6
109. Transfer Fertilize F_6 to Plow S_1
110. Transfer Fertilize F_5 to Plow S_2
111. Buy Corn Seed
112. Buy Soybean Seed
113. Buy Nitrogen
114. Buy Phosphate
115. Buy Potash
116. Buy Liquid Fuel
117. Transfer Disc F_4 to Plow S_3
118. Transfer Disc F_4 to Plow S_4
119. Transfer Disc F_4 to Plow S_5
120. Transfer Disc F_5 to Plow S_3
121. Transfer Disc F_5 to Plow S_4
122. Transfer Disc F_5 to Plow S_5
123. Transfer Disc F_6 to Plow S_3
124. Transfer Disc F_6 to Plow S_4
125. Transfer Disc F_6 to Plow S_5
126. Plow S_3
127. Plow S_4
128. Plow S_5

129. Transfer Plow F_4 to SBP S_3
130. Transfer Plow F_4 to SBP S_4
131. Transfer Plow F_4 to SBP S_5
132. Transfer Plow F_5 to SBP S_3
133. Transfer Plow F_5 to SBP S_4
134. Transfer Plow F_5 to SBP S_5
135. Transfer Plow F_6 to SBP S_3
136. Transfer Plow F_6 to SBP S_4
137. Transfer Plow F_6 to SBP S_5
138. Transfer Plow S_1 to SBP S_3
139. Transfer Plow S_1 to SBP S_4
140. Transfer Plow S_1 to SBP S_5
141. Transfer Plow S_2 to SBP S_3
142. Transfer Plow S_2 to SBP S_4
143. Transfer Plow S_2 to SBP S_5
144. Transfer Plow S_3 to SBP S_3
145. Transfer Plow S_3 to SBP S_4
146. Transfer Plow S_3 to SBP S_5
147. Transfer Plow S_4 to SBP S_4
148. Transfer Plow S_4 to SBP S_5
149. Transfer Plow S_5 to SBP S_5
150. Seed Bed Preparation S_3
151. Seed Bed Preparation S_4
152. Seed Bed Preparation S_5
153. Transfer SBP S_3 to Plant S_3
154. Transfer SBP S_3 to Plant S_4
155. Transfer SBP S_3 to Plant S_5
156. Transfer SBP S_4 to Plant S_4
157. Transfer SBP S_4 to Plant S_5
158. Transfer SBP S_5 to Plant S_5
159. Transfer Fertilize F_4 to Plow S_3
160. Transfer Fertilize F_4 to Plow S_4
161. Transfer Fertilize F_4 to Plow S_5
162. Transfer Fertilize F_5 to Plow S_3
163. Transfer Fertilize F_5 to Plow S_4
164. Transfer Fertilize F_5 to Plow S_5
165. Transfer Fertilize F_6 to Plow S_3
166. Transfer Fertilize F_6 to Plow S_4
167. Transfer Fertilize F_6 to Plow S_5
168. Hire Labor S_7
169. Plant Corn (Dry) S_1 Harvest F_3
170. Plant Corn (Dry) S_1 Harvest F_4
171. Plant Corn (Dry) S_1 Harvest F_5
172. Plant Corn (Dry) S_2 Harvest F_4
173. Plant Corn (Dry) S_2 Harvest F_5
174. Plant Corn (Dry) S_3 Harvest F_4
175. Plant Corn (Dry) S_3 Harvest F_5
176. Sell Dry Corn

177. Sell Soybeans

178. Buy Btu's

179. Buy Silage Storage

180. Buy High Moisture Corn Storage

181. Buy 450# Steers

182. Feed Cattle - 1%, Soy and Urea

183. Feed Cattle - 1%, Soy Only

184. Feed Cattle - 1%, DDGS and Urea

185. Feed Cattle - 1%, DDGS Only

186. Feed Cattle - 2 Phase, Soy and Urea

187. Feed Cattle - 2 Phase, Soy Only

188. Feed Cattle - 2 Phase, DDGS and Urea

189. Feed Cattle - 2 Phase, DDGS Only

190. Feed Cattle - 44 Meal, Soy and Urea

191. Feed Cattle - 44 Meal, Soy Only

192. Feed Cattle - 44 Meal, DDGS and Urea

193. Feed Cattle - 44 Meal, DDGS Only

194. Feed Cattle - 63 Meal, Soy and Urea

195. Feed Cattle - 63 Meal, Soy Only

196. Feed Cattle - 63 Meal, DDGS Only

197. Sell 1050# Steers

198. Buy SBM

199. Buy Corn

200. Buy Urea

201. Buy Limestone

202. Buy Dical

203. Buy Feedlot Space

204. Transfer Manure N to Fertilizer N

205. Transfer Manure P to Fertilizer P

206. Transfer Manure K to Fertilizer K

207. Buy Ethanol Production Capacity (Interest)

208. Produce Ethanol 12/2-4/19

209. Produce Ethanol 4/20-7/1

210. Produce Ethanol 7/2-8/30

211. Produce Ethanol 8/31-12/1

212. Sell Ethanol

213. Sell DDGS

214. Transfer Ethanol to Liquid Fuel

215. Labor Transfer S_1

216. Labor Transfer S_2

217. Labor Transfer S_3

218. Labor Transfer S_4

219. Labor Transfer S_5

220. Labor Transfer S_6

221. Labor Transfer S_7

222. Labor Transfer F_1

223. Labor Transfer F_2

224. Labor Transfer F_3

225. Labor Transfer F_4

226. Labor Transfer F_5

227. Labor Transfer F_6

228. Sell Labor 12/2-4/19

229. Sell Labor S_1

230. Sell Labor S_2

231. Sell Labor S_3

232. Sell Labor S_4

233. Sell Labor S_5

234. Sell Labor S_6

235. Sell Labor S_7

236. Sell Labor 7/2-8/30

237. Sell Labor F_1

238. Sell Labor F_2

239. Sell Labor F_3

240. Sell Labor F_4

241. Sell Labor F_5

242. Sell Labor F_6

243. Buy Ethanol Production Capacity (Depreciation)

Constraints (189)

1. Upper Bound on Soybean Land
2. Upper Bound on Corn Land
3. Upper Bound on Silage Land
4. Field Labor 12/2 - 4/29
5. Field Labor S_1
6. Field Labor S_2
7. Field Labor S_3
8. Field Labor S_4
9. Field Labor S_5
10. Field Labor S_6
11. Field Labor 7/2 - 8/30
12. Field Labor F_1
13. Field Labor F_2
14. Field Labor F_3
15. Field Labor F_4
16. Field Labor F_5
17. Field Labor F_6
18. Hired Labor 12/2 - 4/19
19. Hired Labor S_1
20. Hired Labor S_2
21. Hired Labor S_3
222. Hired Labor S_4
23. Hired Labor S_5
24. Hired Labor S_6
25. Hired Labor 7/2 - 8/30
26. Hired Labor F_1
27. Hired Labor F_2
28. Hired Labor F_3
29. Hired Labor F_4
30. Hired Labor F_5
31. Hired Labor F_6
32. Full Time Hired Labor
33. Harvest F_3 to Disc Transfer
34. Harvest F_4 to Disc Transfer
35. Harvest F_5 to Disc Transfer
36. Disc and Fertilize F_4
37. Disc and Fertilize F_5
38. Disc and Fertilize F_6
39. Field Time Constraint - Disc F_4
40. Field Time Constraint - Disc F_5
41. Field Time Constraint - Disc F_6
42. Disc F_4 to Plow Transfer
43. Disc F_5 to Plow Transfer
44. Disc F_6 to Plow Transfer
45. Plow F_4
46. Plow F_5
47. Plow F_6
48. Plow S_1
49. Plow S_2
50. Field Time Constraint - Plow F_4

51. Field Time Constraint - Plow F_5
52. Field Time Constraint - Plow F_6
53. Field Time Constraint - Plow S_1
54. Field Time Constraint - Plow S_2
55. Plow F_4 to SBP Transfer
56. Plow F_5 to SBP Transfer
57. Plow F_6 to SBP Transfer
58. Plow S_1 to SBP Transfer
59. Plow S_2 to SBP Transfer
60. Seedbed Preparation S_1
61. Seedbed Preparation S_2
62. Field Time Constraint - SBP S_1
63. Field Time Constraint - SBP S_2
64. SBP S_1 to Plant Transfer
65. SBP S_2 to Plant Transfer
66. Plant S_1
67. Plant S_2
68. Plant S_3
69. Field Time Constraint - Plant S_1
70. Field Time Constraint - Plant S_2
71. Field Time Constraint - Plant S_3
72. Field Time Constraint - Plant S_4
73. Field Time Constraint - Plant S_5
74. Field Time Constraint - Cultivate S_5
75. Field Time Constraint - Cultivate S_6
76. Harvest F_1 to Fertilize Transfer
77. Harvest F_2 to Fertilize Transfer
78. Harvest F_3 to Fertilize Transfer
79. Harvest F_4 to Fertilize Transfer
80. Fertilize F_4
81. Fertilize F_5
82. Fertilize F_6
83. Fertilize F_4 to Plow Transfer
84. Fertilize F_5 to Plow Transfer
85. Fertilize F_6 to Plow Transfer
86. Plant S_4
87. Plant S_5
88. Corn Seed Balance
89. Soybean Seed Balance
90. Fertilizer (NH_3) Balance
91. Fertilizer (P_2O_5) Balance
92. Fertilizer (K_2O) Balance
93. Liquid Fuel Balance
94. Plow S_3
95. Plow S_4
96. Plow S_5
97. Field Time Constraint - Plow S_3
98. Field Time Constraint - Plow S_4
99. Field Time Constraint - Plow S_5
100. Plow S_3 to SBP Transfer

101. Plow S_4 to SBP Transfer
102. Plow S_5 to SBP Transfer
103. Seedbed Preparation S_3
104. Seedbed Preparation S_4
105. Seedbed Preparation S_5
106. Field Time Constraint - SBP S_3
107. Field Time Constraint - SBP S_4
108. Field Time Constraint - SBP S_5
109. SBP S_3 to Plant Transfer
110. SBP S_4 to Plant Transfer
111. SBP S_5 to Plant Transfer
112. Tractor Time Constraint S_1
113. Tractor Time Constraint S_2
114. Tractor Time Constraint S_3
115. Tractor Time Constraint S_4
116. Tractor Time Constraint S_5
117. Field Labor S_7
118. Hired Labor S_7
119. Field Time Constraint - Cultivate S_7
120. Lower Bound on Soybean Land
121. Lower Bound on Corn Land
122. Lower Bound on Silage Land
123. Total Land Constraint
124. Soybean Balance
125. High Moist Corn Balance
126. Dry Corn Balance
127. Corn Silage Balance
128. Btu Balance
129. Field Time Constraint - Harvest F_1
130. Field Time Constraint - Harvest F_2
131. Field Time Constraint - Harvest F_3
132. Field Time Constraint - Harvest F_4
133. Field Time Constraint - Harvest F_5
134. Silage Storage Capacity
135. High Moisture Corn Storage Capacity
136. 450# Feeder Steer Balance
137. 1050# Fed Steer Balance
138. Soybean Meal Balance
139. Urea Balance
140. Limestone Balance
141. Dical Balance
142. DDGS Balance
143. Feedlot Space Constraint
144. Manure N Balance
145. Manure P Balance
146. Manure K Balance
147. Non-Field Labor S_1
148. Non-Field Labor S_2
149. Non-Field Labor S_3
150. Non-Field Labor S_4

151. Non-Field Labor S_5
152. Non-Field Labor S_6
153. Non-Field Labor S_7
154. Non-Field Labor F_1
155. Non-Field Labor F_2
156. Non-Field Labor F_3
157. Non-Field Labor F_4
158. Non-Field Labor F_5
159. Non-Field Labor F_6
160. Ethanol Production Capacity 12/2 - 4/19
161. Ethanol Balance
162. Ethanol Production Capacity 4/20 - 7/1
163. Ethanol Production Capacity 7/2 - 8/30
164. Ethanol Production Capacity 8/31 - 12/1
165. Upper Bound on Ethanol Production
166. Upper Bound on Feedlot Capacity
167. Upper Bound on Rented Land
168. Upper Bound on Land Rented Out
169. Upper Bound on Selling Dry Corn
170. Upper Bound on Selling Soybeans
171. Upper Bound on Selling Steers
172. Upper Bound on Selling Alcohol
173. Upper Bound on Selling DDGS
174. Labor Selling Constraint 12/2 - 4/19
175. Labor Selling Constraint S_1
176. Labor Selling Constraint S_2
177. Labor Selling Constraint S_3
178. Labor Selling Constraint S_4
179. Labor Selling Constraint S_5
180. Labor Selling Constraint S_6
181. Labor Selling Constraint S_7
182. Labor Selling Constraint 7/2 - 8/30
183. Labor Selling Constraint F_1
184. Labor Selling Constraint F_2
185. Labor Selling Constraint F_3
186. Labor Selling Constraint F_4
187. Labor Selling Constraint F_5
188. Labor Selling Constraint F_6
189. Ethanol Production Unit Depreciation

APPENDIX C

DETERMINING WHAT PRICE TO USE TO REPRESENT A TIME PERIOD WHERE PRICES ARE CHANGING

DETERMINING WHAT PRICE TO USE TO REPRESENT A TIME PERIOD WHERE PRICES ARE CHANGING

When using a linear programming (LP) model which represents a point in time a more dynamic view of the problem may be desirable. This would be the case when one wishes to use the model for decision making affecting a longer period, say 10 to 15 years. In order to do this, prices must be entered into the model which would be representative of the chosen time period. One approach to this problem would be to treat the price as one would an annuity return for a replacement investment.

Using the approach adopted by Harsh, Connor, Schwab, 1981, for analyzing replacement investments would give a value which could be interpreted as the price one would be indifferent to paying throughout a period when compared to paying the predicted values for the item during the same time span. This "present value" of a commodity could be determined for all the inputs and outputs of the model and thus depict a dynamic decision making tool. It is best to examine this procedure through the use of an example.

The price of gasoline over the next ten years is used to demonstrate this concept (Table C.1). To initiate the process, one must first arrive at a discount factor based on his conception of the prevading inflation rate plus a risk factor. Ten percent is used here only as an example. Table C.2 lists the values for a variety of discount factors. Once the discounted prices are calculated they are then summed as

Table C.1

Determining the Present Value for a Stream of Future Gasoline Prices

Year	Price $/gal	Discount Factor (10%)	Discounted Price (col. 1 x col. 2)	Accumulated Discounted Price	Annuity Factor (10%)	Indif-ference Price (col. 4 x col. 5)
1980	1.20	1.000	1.200	1.200	1.100	1.32
1981	1.35	.909	1.227	2.427	.576	1.40
1982	1.52	.826	1.256	3.683	.402	1.48
1983	1.73	.751	1.299	4.982	.315	1.57
1984	1.92	.683	1.311	6.293	.264	1.66
1985	2.05	.621	1.273	7.566	.230	1.74
1986	2.21	.564	1.246	8.814	.205	1.81
1987	2.36	.513	1.210	10.022	.187	1.87
1988	2.55	.467	1.191	11.213	.174	1.95
1989	2.76	.424	1.170	12.383	.163	2.02
1990	2.91	.386	1.123	13.506	.154	2.08

accumulated price. Each succeeding price is added to the total of all the preceding prices. Any one year's accumulated discounted price would equal the sum of the discounted prices for all the previous years plus the discounted price of that particular year.

The final step is to standardize the price by multiplying the accumulated discounted prices by an annuity factor equal to the discount factor used, in this case 10%. Table C.3 lists the present worth of an annuity factor. The annuity factor can be obtained by dividing 1 by the value listed. This would give you the amount that would be equal to receiving one dollar today if that amount were to be received each year for the given period (i.e., I would be indifferent between receiving $1.00 today and receiving $.163 (1 ÷ 6.145) for 10 years when a 10% inflation and risk value is used).

The indifference price (accumulated discounted price x annuity factor) would be a price representative of the changing price of gasoline over the years between the first year listed (1980) and the last year of the time period desired. For illustration, the indifference price for the years 1980 to 1988, inclusive, would be $1.95 (Table C.1).

TABLE C-2

DISCOUNT FACTOR—How much 1 at a future date is worth today.

Year	1%	3%	5%	6%	8%	10%	12%	14%	15%	16%	18%	20%	22%	24%	25%	26%	28%	30%	35%	40%	45%	50%	Year
1	.990	.971	.952	.943	.926	.909	.893	.877	.870	.862	.847	.833	.820	.806	.800	.794	.781	.769	.741	.714	.690	.667	1
2	.980	.943	.907	.890	.857	.826	.797	.769	.756	.743	.718	.694	.672	.650	.640	.630	.610	.592	.549	.510	.476	.444	2
3	.971	.915	.864	.840	.794	.751	.712	.675	.658	.641	.609	.579	.551	.524	.512	.500	.477	.455	.406	.364	.328	.296	3
4	.961	.888	.823	.792	.735	.683	.636	.592	.572	.552	.516	.482	.451	.423	.410	.397	.373	.350	.301	.260	.226	.198	4
5	.951	.863	.784	.747	.681	.621	.567	.519	.497	.476	.437	.402	.370	.341	.328	.315	.291	.269	.223	.186	.156	.132	5
6	942	.837	.746	.705	.630	.564	507	.456	.432	.410	.370	.335	.303	.275	.262	.250	.227	.207	.165	.133	.108	.088	6
7	.933	.813	.711	.665	.583	.513	.452	.400	.376	.354	.314	.279	.249	.222	.210	.198	.178	.159	.122	.095	.074	.059	7
8	.923	.789	.677	.627	.540	.467	.404	.351	.327	.305	.266	.233	.204	.179	.168	.157	.139	.123	.091	.068	.051	039	8
9	.914	.766	.645	.592	.500	.424	.361	.308	.284	.263	.225	.194	.167	.144	.134	.125	.108	.094	.067	.048	.035	.026	9
10	.905	.744	.614	.558	.463	.386	.322	.270	.247	.227	.191	.162	.137	.116	.107	.099	.085	.073	.050	.035	.024	.017	10
11	.896	.722	.585	.527	.429	.350	.287	.237	.215	.195	.162	.135	.112	.094	.086	.079	.066	.056	.037	.025	.017	.012	11
12	.887	.701	.557	.497	.397	.319	.257	.208	.187	.168	.137	.112	.092	.076	.069	.062	.052	.043	.027	.018	.012	.008	12
13	.879	.681	.530	.469	.368	.290	.229	.182	.163	.145	.116	.093	.075	.061	.055	.050	.040	.033	.020	.013	.008	.005	13
14	.870	.661	.505	.442	.340	.263	.205	.160	.141	.125	.099	.078	.062	.049	.044	.039	.032	.025	.015	.009	006	.003	14
15	.861	.642	.481	.417	.315	.239	.183	.140	.123	.108	.084	.065	.051	.040	.035	.031	.025	.020	.011	.006	.004	.002	15
16	.853	.623	.458	.394	.292	.218	.163	.123	.107	.093	.071	.054	.042	.032	.028	.025	.019	.015	.008	.005	.003	.002	16
17	.844	.605	.436	.371	.270	.198	.146	.108	.093	.080	.060	.045	.034	.026	.023	020	.015	.012	.006	.003	.002	.001	17
18	.836	.587	.416	.350	.250	.180	.130	.095	.081	.069	.051	.038	.028	.021	.018	.016	.012	.009	.005	.002	.001	.001	18
19	.828	570	.396	.331	.232	.164	.116	083	.070	.060	.043	.031	.023	.017	.014	.012	.009	.007	.003	.002	.001	.000	19
20	.820	.554	.377	.312	.215	.149	.104	.073	.061	.051	.037	.026	.019	.014	.012	.010	.007	.005	.002	.001	.001	.000	20
21	.811	.538	.359	.294	.199	.135	.093	.064	.053	.044	.031	.022	.015	.011	.009	.008	.006	.004	.002	.001	.000	.000	21
22	.803	.522	.342	.278	.184	.123	.083	.056	.046	.038	.026	.018	.013	.009	.007	.006	.004	.003	.001	.001	.000	000	22
23	.795	.507	.326	.262	.170	.112	.074	.049	.040	.033	.022	.015	.010	.007	.006	.005	.003	.002	.001	.000	.000	.000	23
24	.788	.492	.310	.247	.158	.102	.066	.043	.035	.028	.019	.013	.008	.006	.005	.004	.003	.002	.001	.000	.000	.000	24
25	.780	.478	.295	.233	.146	.092	.059	.038	.030	.024	.016	.010	.007	.005	.004	.003	.002	.001	.001	.000	.000	.000	25
26	.772	.464	.281	.220	.135	.084	.053	.033	.026	.021	.014	.009	.006	.004	.003	002	.002	.001	.000	.000	.000	.000	26
27	.764	.450	.268	.207	.125	.076	.047	.029	.023	.018	.011	.007	.005	.003	.802	.002	.001	.001	.000	.000	.000	.000	27
28	.757	.437	.255	.196	.116	.069	.042	.026	.020	.016	.010	.006	.004	.002	.002	.002	.001	.001	.000	.000	.000	.000	28
29	.749	.424	.243	.185	.107	.063	.037	.022	.017	.014	.008	.005	.003	.002	.002	.001	.001	.000	.000	.000	.000	.000	29
30	.742	.412	.231	.174	.099	.057	.033	.020	.015	.012	.007	.004	.003	.002	.001	.001	.001	.000	.000	.000	.000	.000	30
35	.706	.355	.181	.130	.068	.036	.019	.010	.008	.006	.003	.002	.001	.001	.000	.000	.000	.000	.000	.000	.000	.000	35
40	.672	.307	.142	.097	.046	.022	.011	.005	.004	.003	.001	.001	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	40
45	.639	.264	.111	.073	.031	.014	.006	.003	.002	.001	.001	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	000	45
50	608	.228	.087	.054	.021	.009	.003	.001	.001	.001	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	50

TABLE C.3

PRESENT WORTH OF AN ANNUITY FACTOR—

How much 1 received or paid annually for X years is worth today.

Year	1%	3%	5%	6%	8%	10%	12%	14%	15%	16%	18%	20%	22%	24%	25%	26%	28%	30%	35%	40%	45%	50%	Year
1	.990	.971	.952	.943	.926	.909	.893	.877	.870	.862	.847	.833	.820	.806	.800	.794	.781	.769	.741	.714	.690	.667	1
2	1.970	1.913	1.859	1.833	1.783	1.736	1.690	1.647	1.626	1.605	1.566	1.528	1.492	1.457	1.440	1.424	1.392	1.361	1.289	1.224	1.165	1.111	2
3	2.941	2.829	2.723	2.673	2.577	2.487	2.402	2.322	2.283	2.246	2.174	2.106	2.042	1.981	1.952	1.923	1.868	1.816	1.696	1.589	1.493	1.407	3
4	3.902	3.717	3.546	3.465	3.312	3.170	3.037	2.914	2.855	2.798	2.690	2.589	2.494	2.404	2.362	2.320	2.241	2.166	1.997	1.849	1.720	1.605	4
5	4.853	4.580	4.329	4.212	3.993	3.791	3.605	3.433	3.352	3.274	3.127	2.991	2.864	2.745	2.689	2.635	2.532	2.436	2.220	2.035	1.876	1.737	5
6	5.795	5.417	5.076	4.917	4.623	4.355	4.111	3.889	3.784	3.685	3.498	3.326	3.167	3.020	2.951	2.885	2.759	2.643	2.385	2.168	1.983	1.824	6
7	6.728	6.230	5.786	5.582	5.206	4.868	4.564	4.288	4.160	4.039	3.812	3.605	3.416	3.242	3.161	3.083	2.937	2.802	2.508	2.263	2.057	1.883	7
8	7.652	7.020	6.463	6.210	5.747	5.335	4.968	4.639	4.487	4.344	4.078	3.837	3.619	3.421	3.329	3.241	3.076	2.925	2.598	2.331	2.108	1.922	8
9	8.566	7.786	7.108	6.802	6.247	5.759	5.328	4.946	4.772	4.607	4.303	4.031	3.786	3.566	3.463	3.366	3.184	3.019	2.665	2.379	2.144	1.948	9
10	9.471	8.530	7.722	7.360	6.710	6.145	5.650	5.216	5.019	4.833	4.494	4.192	3.923	3.682	3.571	3.465	3.269	3.092	2.715	2.414	2.168	1.965	10
11	10.368	9.253	8.306	7.887	7.139	6.495	5.938	5.453	5.234	5.029	4.656	4.327	4.035	3.776	3.656	3.543	3.335	3.147	2.752	2.438	2.185	1.977	11
12	11.255	9.954	8.863	8.384	7.536	6.814	6.194	5.660	5.421	5.197	4.793	4.439	4.127	3.851	3.725	3.606	3.387	3.190	2.779	2.456	2.196	1.985	12
13	12.134	10.635	9.394	8.853	7.904	7.103	6.424	5.842	5.583	5.342	4.910	4.533	4.203	3.912	3.780	3.656	3.427	3.223	2.799	2.469	2.204	1.990	13
14	13.004	11.296	9.899	9.295	8.244	7.367	6.628	6.002	5.724	5.468	5.008	4.611	4.265	3.962	3.824	3.695	3.459	3.249	2.814	2.478	2.210	1.993	14
15	13.865	11.938	10.380	9.712	8.559	7.606	6.811	6.142	5.847	5.575	5.092	4.675	4.315	4.001	3.859	3.726	3.483	3.268	2.825	2.484	2.214	1.995	15
16	14.718	12.561	10.838	10.106	8.851	7.824	6.974	6.265	5.954	5.668	5.162	4.730	4.357	4.033	3.887	3.751	3.503	3.283	2.834	2.489	2.216	1.997	16
17	15.562	13.166	11.274	10.477	9.122	8.022	7.120	6.373	6.047	5.749	5.222	4.775	4.391	4.059	3.910	3.771	3.518	3.295	2.840	2.492	2.216	1.998	17
18	16.398	13.754	11.690	10.828	9.372	8.201	7.250	6.467	6.128	5.818	5.273	4.812	4.419	4.080	3.928	3.786	3.529	3.304	2.844	2.494	2.219	1.999	18
19	17.226	14.324	12.085	11.158	9.604	8.365	7.366	6.550	6.198	5.877	5.316	4.843	4.442	4.097	3.942	3.799	3.539	3.311	2.848	2.496	2.220	1.999	19
20	18.046	14.877	12.462	11.470	9.818	8.514	7.469	6.623	6.259	5.929	5.353	4.870	4.460	4.110	3.954	3.808	3.546	3.316	2.850	2.497	2.221	1.999	20
21	18.857	15.415	12.821	11.764	10.017	8.649	7.562	6.687	6.312	5.973	5.384	4.891	4.476	4.121	3.963	3.816	3.551	3.320	2.852	2.498	2.221	2.000	21
22	19.660	15.937	13.163	12.042	10.201	8.772	7.645	6.743	6.359	6.011	5.410	4.909	4.488	4.130	3.970	3.822	3.556	3.323	2.853	2.498	2.222	2.000	22
23	20.456	16.444	13.489	12.303	10.371	8.883	7.718	6.792	6.399	6.044	5.432	4.925	4.499	4.137	3.976	3.827	3.559	3.325	2.854	2.499	2.222	2.000	23
24	21.243	16.936	13.799	12.550	10.529	8.985	7.784	6.835	6.434	6.073	5.451	4.937	4.507	4.143	3.981	3.831	3.562	3.327	2.855	2.499	2.222	2.000	24
25	22.023	17.413	14.094	12.783	10.675	9.077	7.843	6.873	6.464	6.097	5.467	4.948	4.514	4.147	3.985	3.834	3.564	3.329	2.856	2.499	2.222	2.000	25
26	22.795	17.877	14.375	13.003	10.810	9.161	7.896	6.906	6.491	6.118	5.480	4.956	4.520	4.151	3.988	3.837	3.566	3.330	2.856	2.500	2.222	2.000	26
27	23.560	18.327	14.643	13.211	10.935	9.237	7.943	6.935	6.514	6.136	5.492	4.964	4.524	4.154	3.990	3.839	3.567	3.331	2.856	2.500	2.222	2.000	27
28	24.316	18.764	14.898	13.406	11.051	9.307	7.984	6.961	6.534	6.152	5.502	4.970	4.528	4.157	3.992	3.840	3.568	3.331	2.857	2.500	2.222	2.000	28
29	25.066	19.188	15.141	13.591	11.158	9.370	8.022	6.983	6.551	6.166	5.510	4.975	4.531	4.159	3.994	3.841	3.569	3.332	2.857	2.500	2.222	2.000	29
30	25.808	19.600	15.372	13.765	11.258	9.427	8.055	7.003	6.566	6.177	5.517	4.979	4.534	4.160	3.995	3.842	3.569	3.332	2.857	2.500	2.222	2.000	30
35	29.409	21.487	16.374	14.498	11.655	9.644	8.176	7.070	6.617	6.215	5.539	4.992	4.541	4.164	3.998	3.845	3.571	3.333	2.857	2.500	2.222	2.000	35
40	32.835	23.115	17.159	15.046	11.925	9.779	8.244	7.105	6.642	6.233	5.548	4.997	4.544	4.166	3.999	3.846	3.571	3.333	2.857	2.500	2.222	2.000	40
45	36.095	24.519	17.774	15.456	12.108	9.863	8.283	7.123	6.654	6.242	5.552	4.999	4.545	4.166	4.000	3.846	3.571	3.333	2.857	2.500	2.222	2.000	45
50	39.196	25.730	18.256	15.762	12.233	9.915	8.304	7.133	6.661	6.246	5.554	4.999	4.545	4.167	4.000	3.846	3.571	3.333	2.857	2.500	2.222	2.000	50

APPENDIX D

ETHANOL PRODUCTION PROTOCOL

ETHANOL PRODUCTION PROTOCOL

Introduction

Michigan State University researchers, with support from the Michigan Department of Agriculture, have designed and constructed and are operating a pilot scale ethanol production system; research is the primary focus. The system has consistently yielded around 2.5 gallons of ethanol/bushel of No. 2 corn when proper end point controls are used. Although this is often taken for granted as the standard yield, most farm scale production systems report yields between 1.5 and 2.0 gallons/bushel. Qualify control is an essential key to realizing higher yield.

The procedures practiced at the MSU unit are detailed (actual description of the processing of a batch on October 24 and 28, 1980). These procedures for properly designed systemd should give ethanol yields of 2.40 to 2.55 gallons (moisture free basis) per bushel of No. 2 corn. Also, the procedure outlined can be used to estimate labor requirements.

Fermentation

Corn that has been ground using a 1/2 inch screen is used as a feedstock.

8:00-8:30 a.m. The cook tank was cleaned and readied for use. Initially, 2000 pounds of water are placed in the cook tank. This is slightly more than 50% of the needed water, but is adequate for receiving the ground corn.

8:30-9:00 a.m. Auger and weigh 1000 pounds of ground corn into the cooker. This is 17.9 bushels of No. 2 corn; ultimately 450 gallons (25 gallons/bushel corn) of water are required for proper fermentation. However, during the cooking stage, only 322 gallons (18 gallons/bushel) are used. This reduces the energy for cooking and allows the remaining 125 gallons (7 gallons/bushel) to be added following the cooking stage to increase the rate of cooling. After the corn is in the cooker, 653 pounds of water are added to bring the water to 18 gallons/bushel.

If cooling or condensing water is saved from some other source in the system, the water should be used for cooking and not for cooling purposes. Contaminants in the water are sterilized at higher cooking temperatures while they could hinder fermentation if introduced at lower temperatures.

9:00-10:05 a.m. Raise temperature from 55^{o}F (12.8^{o}C) to 212^{o}F (100^{o}C). During this process, the pH is adjusted to 6.5 using hydrated lime, ammonia solution or 50% sulfuric acid. Once the target pH is reached, the enzyme "taka-therm" is added at a rate of .15% of the dry starch in the ground grain. There is 68% starch (moisture free basis) in corn. For a bushel of 15.5% moisture corn, the calculations are

$$56 \times .845 \times .68 \times .0015 = .048 \text{ lb.}$$

To convert this to grams, recall there are 454 grams/ pound. Thus,

$.048 \times 454 = \text{grams/bushel}$

For liquid measurement the conversion is

1.2 grams = 1 milliliter

The mash thins upon adding the enzyme.

10:05-11:35 a.m. The mash is cooked at a gentle boil for 1.5 hours. Note: use of a pressure cooker in the cooking phase could reduce cooking time to 15 minutes.

11:35-11:50 a.m. Cool to 194^{o}F (90^{o}C). This is done by adding water, not to exceed 7 gallons per bushel (in this case 1,032 lbs). It is usually not necessary to add the full amount of water to achieve the desired cooling. Check pH, and if needed, adjust the pH to 6.5. When the mash is cooled and the pH is stable at 6.5, again add "taka-therm" at a rate of .20% (moisture free basis) of the starch in the corn.

11:50-1:05 p.m. Completion of the liquification stage. After adding the second dose of "taka-therm," hydrolization of starch can take anywhere from one to four hours. The endpoint is measured by an iodine test which indicates the absence of starch. Using the iodine indicator, a positive test is signaled by a blue color. A negative test for starch will be indicated by a brown or amber color.

1:05-2:05 p.m. Cool mash to 134^{O}F (56.7^{O}C). After the hydrolysis of the starch, water is run through the steam pipes to lower temperature. At this time, the pH is lowered to 4.2 by adding 50% sulfuric acid solution. A pH range of 4 to 4.4 is considered best for the enzyme "diazyme" and saccharification to work.

2:05 p.m. Diazyme is added. Mash was cooled and pH was 4.2. Diazyme was added at a rate of .3% (moisture free basis) of the starch in the corn.

2:05-3:35 p.m. Saccharification. Conversion of the poly-saccharides to mono-saccharides takes place while maintaining the temperature at 134^{O}F (57^{O}C). Again, end point analysis is used to determine the completion of this stage although it is not as critical here. When the glucose reaches 7 to 8%, the mash is again cooled. Break down of the poly-saccharides will continue during early afermentation at a much slower rate usually reaching a concentration of near 12%.

3:35-4:15 p.m. Cooling to 90^{O}F (32^{O}C). Water is added to bring the full mixture to 25 gallons of water per bushel of corn. This did not lower the temperature to the desired 90^{O}F (32^{O}C) so water was passed through the steam pipes as well. It is necessary to reach this temperature because any higher temperature would be detrimental to the yeast. During the cooling process, the yeast is made active by hydrolization with water or a portion of the mash. The latter can cause too much foaming and become messy to work with.

4:15 p.m. The mash was 90^{o}F, yeast was added at a rate of .5% (moisture free basis) of the starch in the corn, and the vat was left to ferment for approximately 2.5 days. The narrow temperature range of 88F to 90F has appeared to be the most desirable for fermentation. The end point of fermentation is determined by the absence of glucose in the mash. A sensitive test for glucose is the clini-test which is used to analyze urine for the presence of glucose.

Note: Agitation throughout the mixing and cooking processes was constant and virogous. For the fermentation stage, the agitator was slowed but remained on. All pH levels need to be monitored continuously and maintained at desired levels throughout the procedures. Furthermore it is critical that the beer is cooled to the temperatures specified before adding the enzymes. Enzymes are natural organic catalysts that facilitate reactions and are denatured at higher temperatures.

Distillation

In order to estimate the ethanol yield per bushel of corn, the fermented mash was weighed to determine the weight loss from the CO_2 dispelled into the atmosphere. A weight loss of near 1/3 the weight (moisture free basis) of the corn implied a yield of near 2.5 gallons per bushel. The ethanol concentration in the mash was approximately 8%.

9:00-10:00 a.m. The area was cleaned and prepared for distillation. A defective steam trap on the still required attention as well as more general maintenance. If the distillation column were to run continuously the start up time is eliminated and clean-up and maintenance can be conducted as much as possible while the system is running.

10:00-11:00 a.m. Distillation. Ethanol boils at $172^{o}F$ ($78^{o}C$); water boils at $212^{o}F$ ($100^{o}C$). This simple fact allows the two to be separated through a distillation process. During the early stages, the steam and stillage flow rates must be balanced so that the temperature at the bottom of the column is $212^{o}F$ ($100^{o}C$) while maintaining a temperature as close to but not below, $172^{o}F$ ($78^{o}C$) as possible at the top of the column. The procedure is as follows. The column is preheated with steam and water. This insures a uniform temperature throughout this glass column and provides a means of stripping the ethanol from the initial flow of beer. The beer is introduced to the distillation column from the top. Since this column is a plated design (as opposed to packed) it is possible to pass the whole stillage through without plugging. This eliminates the need to separate the grains from the beer prior to distillation.

If the column is properly preheated, the alcohol has vaporized before the mash reaches the bottom. Steam is passed through the heat coils to maintain a temperature of 212^{o}F (100^{o}C) the boiling point of water. Toward the upper end of the column, the cooler temperature condenses the water vapor but allows the ethanol vapors to continue to rise since it vaporizes at a lower temperature then water.

The column as ten plates, nine of which are active. The top plate functions as a means to preheat the incoming beer. Each plate has several holes in it and a pipe (downcomer) leading to the next plate. The pressure of the rising vapors prevents the beer from passing through the holes, but instead forces it downward through the downcomers. As the beer moves from plate to plate the alcohol is vaporized, rises, and is removed from the top of the column. Temperature is usually around 190^{o}F (88^{o}C) near the top. The closer this temperature is to 172^{o}F (78^{o}C) the nearer the ethanol yielded is to 100%. At 190°F, the percentage alcohol is around 70%, or 140 proof.

The alcohol is condensed in a copper and brass condenser with water which is saved for later use in the cooker. Whole stillage is removed from the bottom of the column and screened to separate into grain and thin stillage. The thin stillage is discarded (at the present time) and the grains are saved for storage and handling experiments and for nutritional evaluations.

Once the flow at the top of the column of beer is balanced with the flow of the bottoms (whole stillage) and the steam to give the highest temperature differential between the top and bottom while maintaining 212°F (100°C) at the bottom, the column is "set."

11:00-1:00 p.m. Once the column is set, it must be constantly monitored. This can be done by electronics (at a considerable cost). Currently, at the Beef Research Center clipboard and stopwatch monitoring is used. The column can handle around 50 gallons of stillage per hour. This means that the still must be watched constantly while the 400 odd gallons of stillage is processed. The yield per hour depends on the ethanol content of the beer. At 8% ethanol, the yield per hour would be 5.7 gallons of 140 proof ethanol.

6:00-7:00 p.m.	Clean up and storage of the ethanol and by-product.

Note:	Distillation and preparation of a batch for fermentation at the same time would require the presence of one person at all times. Without controls, this would be quite hectic for one person and it seems that at least some minimal automation would be needed.

BIBLIOGRAPHY

Adams, R. S., 1980, Stillage for Dairy Cattle, Department of Dairy and Animal Science, Pennsylvania State University, University Park, PA.

Bergen, W. G., J. R. Black and D. G. Fox, 1978, A Net Protein System for Predicting Protein Requirements and Feed Protein Values for Growing and Finishing Cattle. Part 2. Constraints of System on NPN Utilization--Upper Limit of Ruminal Microbial Protein Synthesis, Michigan Agricultural Experiment Station Research Report 353:132, Michigan State University, East Lansing, MI.

Black, J. R., J. C. Waller, L. M. Steinmetz and J. W. Ross, 1981a, Economic Value of Fuel Alcohol By-Products: A Focus Upon Distillers Dried Grains with Solubles, Distillers Grains, Distillers Solubles with Potato Distillers Residue, Agricultural Economics Staff Paper No. 81-68, Michigan State University, East Lansing, MI.

Black, J. R., B. Wilkinson, J. Waller, S. Longabaugh and M. Jackson, 1981b, An Examination of the Conditions Under Which Community Scale Ethanol Production Would be Feasible in the Trade Area Served by Mecosta County, Michigan, Department of Agricultural Economics, Michigan State University, East Lansing, MI.

Black, J. R., J. C. Waller and M. Jackson, 1982, Economic Value of Fuel Alcohol By-Products: A Focus Upon Distillers Grains with Solubles, Distillers Grains, Distillers Solubles and Potato Distillers Residue, Michigan Agricultural Experiment Station Research Report 444:126-158, Michigan State University, East Lansing, MI.

Bradley, S. P., A. C. Hax and T. L. Magmanti, 1977, Applied Mathematical Programming, Addison-Wesley Publishing Co., Inc., Philippines.

Brown, H. L., 1980, Business Analysis Summary For Saginaw Valley Cash Crop Farms, 1979, Agricultural Economics Report No. 378, Michigan State University, East Lansing, MI.

Christensen, T., M. Maiwald, D. Easton, J. Currie and B. Rogge, 1980, Distillation of Ethanol From Corn for Energy Use in Agriculture, Department of Agricultural Engineering, Iowa State University, Ames, IA.

Christenson, D. R., 1977, Energy Inputs and Returns from Various Cropping Systems, Cooperative Extension Service, Energy Fact Sheet No. 17, Michigan State University, East Lansing, MI.

David, M. L., R. J. Buzenburg, G. S. Hammaker and H. B. Pfost, 1980, Small Scale Ethanol Production for Fuels, Development Planning and Research Associates, Inc., Manhattan, KS.

Fox, D. G. and J. R. Black, 1977a, A System for Predicting Performance of Growing and Finishing Beef Cattle, Michigan Agricultural Experiment Station Research Report 328:141-162, Michigan State University, East Lansing, MI.

Fox, D. G. and J. R. Black, 1977b, Use of Performance Simulation to Predict Cost of Grain Under Varied Conditions, Michigan Agricultural Experiment Station Report 328:208-215, Michigan State University, East Lansing, MI.

Geiger, J. W., E. A. Grulke and M. C. Hawley, 1981, "Design, Operation and Construction of a Distillation Column for a Small Scale Fermentation Ethanol Plant," Development of a "Controllable" Farm Scale Research Still and Associated Research Package, Michigan State University, East Lansing, MI.

Harsh, S. B., L. J. Connor and G. D. Schwab, 1981, Managing The Farm Business, Prentice-Hall, Inc., Englewood Cliffs, NJ.

Katzen Associates, 1980, Farm and Cooperative Alcohol Plant Study, Technical and Economic Assessment as a Commercial Venture, U. S. National Alcohol Fuels Commission, Department of Energy, Inc., Washington, D.C.

Kelsey, M. P. and A. Johnson, 1979, Business Analysis Summary for Saginaw Cash Crop Farms, 1978, Agricultural Economics Report No. 358, Michigan State University, East Lansing, MI.

Kramer, Mark, 1977, Three Farms, Little, Brown and Company, Boston/Toronto.

Lappe, F. M. and J. Collins, 1977, Food First: Beyond the Myth of Scarcity, Houghton-Mifflin, Boston, MA.

Lehramann, J. A., 1976, Direct Economic Effects of Increased Energy Prices on Optimal Corn and Soybean Production of Cash Grain Farms in Southeastern Michigan, M.S. Thesis, Michigan State University, East Lansing, MI.

Litterman, M., V. Eidman and H. Jensen, 1978, Economics of Gasohol, Economic Report ER 78-10, University of Minnesota, St. Paul, MN.

Meekoff, R., M. Gill and W. Tyner, 1980, Gasohol: Prospects and Implications, Agricultural Economic Report No. 458, Department of Agriculture, ESCS, Washington, D.C.

Michigan Department of Agriculture, 1980, Michigan Agricultural Statistics, Michigan Agricultural Reporting Service, Lansing, MI.

Michigan State University, 1980, MSU Agriculture Model Quarterly Report, Vol. 1, No. 2, Department of Agricultural Economics, Michigan State University, East Lansing, MI.

__________, 1981, MSU Agriculture Model Quarterly Report, Vol. 2, No. 2, Department of Agricultural Economics, Michigan State University, East Lansing, MI.

Wellis, Micki, 1979, Making It On the Farm, American Agricultural News, Washington, D.C.

Newhouse News, 1980, Alternate Fuels Grow More Appealing, Newhouse News Service 1-80, Associated Press International, Washington, D.C.

Ogden, R. L., 1980, "Production Process for Alcohol From Foodstuffs," Ethanol Production and Utilization for Fuel, Cooperative Extension Service Report No. 82:2, University of Nebraska, Lincoln, NE.

Poos, M. I. and T. Klopfenstein, 1979, Nutritional Value of By-Products of Alcohol Production for Livestock Feeds, Cooperative Extension Service Report No. 79:4, University of Nebraska, Lincoln, NE.

Rider, A. R. and D. P. Shelton, 1979, "Ethanol - A Fuel for Agricultural Engines," Ethanol Production and Utilization for Fuel, Cooperative Extension Service Report No. 80:2, University of Nebraska, Lincoln, NE.

Rotz, A., M. Cruz, R. Wilkinson and B. Stout, 1980, Utilization of Alcohol in Spark-Ignition and Diesel Engines, Cooperative Extension Service Bulletin E-1426, Michigan State University, East Lansing, MI.

Scearce, W. K., 1980, Economics of Fuel Alcohol Production on the Farm, Cooperative Extension Service, Vol. 3, No. 6, Oklahoma State University, Stillwater, OK.

Schwab, G. D., S. B. Nott, M. P. Kelsey, A. R. Johnson, Z. R. Helsel and W. C. Search, 1980, Michigan Crops and Livestock Estimated 1980 Budgets, Agricultural Economics Report No. 371, Michigan State University, East Lansing, MI.

Tyner, W. E., 1980, The Potential of Using Biomass for Energy in the United States, Energy Policy and Information Program, Purdue University, West Lafayette, IN.

U.S. Congress, 1979, Gasohol: A Technical Memorandum, Office of Technological Assessment, Library of Congress Card No. 79-600170, Washington, D.C.

U.S.D.A., 1980a, Fact Book of U.S. Agriculture, Miscellaneous Publication No. 1068, Washington, D.C.

__________, 1980b, Feed Situation, ESCS, Fds-279, Washington, D.C.

Vitosh, M. L., R. E. Lucas and J. R. Black, 1979, Effects of Nitrogen Fertilizer on Corn Yield, Cooperative Extension Service Bulletin E-802, Michigan State University, East Lansing, MI.

Waller, J. C., J. R. Black, W. G. Bergen and M. F. Jackson, 1980, Effective Use of Distillers Dried Grains in Feedlot Rations With Emphasis on Protein Consideration, Proceeds of Distillers Feed Conference, 35:29.

Waller, J. C., G. M. Weber, J. R. Black, J. Ross and M. F. Jackson, 1982, The MSU Ethanol Research Project and Complementary Subsystems, Michigan Agricultural Experiment Station Research Report 444:116-125, Michigan State University, East Lansing, MI.

Woody, H. D. and J. R. Black, 1978, Influence of Ration Grain Content on Cost of Feeding, Manure Handling and Storage and Manure Credit, Michigan Agricultural Experiment Station Research Report 353:234-241, Michigan State University, East Lansing, MI.