ECONOMICS OF ON-FARM ETHANOL PRODUCTION

USING SWEET SORGHUM

By

PRASHANT V. BELE

Bachelor of Engineering
University of Pune
Pune, India
1999

Master of Science
Oklahoma State University
Stillwater, Oklahoma, USA.
2003

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2007

ECONOMICS OF ON-FARM ETHANOL PRODUCTION

USING SWEET SORGHUM

Thesis Approved:

Dr. Raymond L. Huhnke (Thesis Advisor)
Dr. Danielle D. Bellmer
Dr. Timothy J. Bowser
Dr. Gordon E. Emslie (Dean of Graduate College)

ACKNOWLEDGEMENTS

First, I would like to express sincere appreciation and gratitude to my advisor Dr. Raymond L. Huhnke for his trust and confidence in me and thank him for the intelligent guidance and foresightedness exhibited present research. Secondly, I would like to express my appreciation and heartfelt thanks to the members of my committee Dr. Danielle D. Bellmer and Dr. Timothy J. Bowser for their support and advice during various stages of this project. A special thank you to my father, mother, Ashish Atre and other family members for their trust and confidence in me during the entire program. I also wish to thank Mr. Bruno G. Cateni for his support, trust and intelligent guidance throughout my studies and work. My thanks to my friends Dr. Rohit Datar, Shashank Bhide, Rohit Medhi, Sameer Kango, John Gaete and Dimple Kundiyana for their unconditional support, encouragement and help.

This research could not have been completed without the cooperation of Mr. Roger V. Sahs (Extension Specialist, Oklahoma State University), for his generosity in providing the necessary building blocks and guidance, ensuring the completion of the project.

My heartfelt thanks to Mr. Wayne Kiner and his staff at Biosystems and Agricultural Engineering Laboratory.

Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

b…………………………………………………………………………Bushel

g……………………………………………………………………………Gram

h……………………………………………………………………………Hour

ha………………………………………………………………………...Hectare

kg……………………………………………………………………...Kilogram

l...Liter

m..Meter

SCE………………………………………………...Sugar conversion efficiency

Btu……………………………………………………….....British thermal unit

$..United States Dollar currency

CHAPTER I

INTRODUCTION

There is a growing need for petroleum throughout the world. As the economy grows, the need for energy grows. Oil has been the major source of energy in the United States (U.S.). The availability of oil at a low price left the research and interest in an alternative fuel source far behind over the years. Recent geopolitical and economical changes have led to a growing need for an alternative fuel source, preferably a renewable one.

The role of oil and petroleum based products in the U.S. economy is notable. The transportation sector is completely dependent on gasoline and diesel which are obtained from oil. According to Energy Information Administration (EIA) 2005 U.S. statistics,

- Net petroleum imports: 12,057,000 barrels/day
- Petroleum consumption: 20,731,000 barrels/day
- U.S. total petroleum exports: 1,048,000 barrels/day
- Dependence on net petroleum imports: 59.8% of the total requirement

Perhaps the most important issue surrounding the status of U.S. transportation fuel is that no one knows how long the world's petroleum resources will last. Adding to the country's vulnerability, the limited domestic petroleum resources do not meet the nation's energy needs. The Persian Gulf holds nearly two-thirds of the worlds known oil reserves. U.S. imports more than 53% of its petroleum from the Persian Gulf. The U.S. Department of Energy (DOE) estimates that this will increase to 75% by the year 2010. It should also be noted that oil imports account for almost half of the U.S. trade deficit, which has an enormous impact on the U.S. economy. Developing a stronger market for biofuels produced in the U.S. will help alleviate the negative implications of the trade deficit and contribute to positive economic trends in the U.S. transportation sector [11].

Today, the most popular alternative to oil is biofuels. Ethanol, king of the challengers to petroleum, is already found blended with gasoline at pumps across the country [1]. As of 2006, ethanol is blended in 45% of the nation's gasoline. It should also be noted that some 6 million flex-fuel vehicles (FFV), capable of burning ethanol blends of up to 85 percent (E85), are in use today [29].

As per Environmental Protection Agency (EPA), Methyl Tertiary Butyl Ether (MTBE) is almost exclusively used in the U.S. as a fuel additive in gasoline because it increases the oxygen content of the gasoline. Most oil refiners have chosen to use MTBE over other oxygenates primarily for its blending characteristics as well as for economic reasons. Due to recent ethanol mandate by the U.S. government plus the environmental concerns associated with MTBE, the demand for ethanol has greatly increased. A primary advantage of ethanol for automobile engine performance is octane enhancement: a 10% blend of ethanol in gasoline raises the octane number by 2.5 points [26].

The overall foreign oil imports reduction initiatives, new energy conservation rules and renewable fuels use mandate established by the U.S. government will require the use of 7.5 billion gallons of ethanol and bio-diesel annually by the year 2012, which translates to nearly 90% increase over today's usage [1].

Considering that there are 110 ethanol refineries operating in 19 states, 63 ethanol biorefineries and 8 expansion projects; the most coveted results of the ethanol ventures are the jobs in the rural areas of the U.S. Currently the ethanol industry is responsible for approximately 200,000 jobs and between 1996 and 2000, it added approximately $51 billion to the U.S. economy. Ethanol production creates domestic jobs in plant construction, operation, maintenance, and support in the surrounding communities. This can have a profound impact on rural America where a decline in employment has placed increasing burdens on U.S. cities, infrastructure and tax base [11] [29].

In this competitive world measured on economics, it is worth mentioning the environmental impact of biofuels. Since the beginning of the Industrial Age, atmospheric levels of carbon dioxide increased 25% with more than half of that increase during the past 30 years. In the U.S., about one third of carbon dioxide emissions result directly from producing and consuming transportation fuels. Ethanol can provide a clean solution on two levels. Plants grown for ethanol production absorb carbon dioxide during growth which reduces atmospheric levels of this greenhouse gas. If 4 billion gallons of ethanol were consumed annually, about 26 million metric tons of carbon dioxide emissions would be eliminated. Ethanol reduces the carbon monoxide produced by combusting gasoline. As an oxygenate, ethanol stimulates more complete combustion, reducing the amount of carbon monoxide that is formed [11].

In the U.S., Ethanol is primarily derived from field corn. New techniques developed by researchers show that ethanol can also be produced from other “biomass” sources such as cornstover, pulpwood, rice straw, switch grass, food processing waste, and even municipal solid waste [11]. Considering the spike in ethanol demand and increased corn demand, industry should expect the corn price per bushel and the demand to go higher over a period of time. To meet the exponential ethanol demand, in the U.S., it would be logical to promote other crops and processes for ethanol production other than corn.

Sugar cane is the first and most attractive choice when researchers try to find an alternative for field corn. While considering a crop for ethanol potential, it would be worth considering the impact of diverting that crop’s production to ethanol. In the case of corn farmers they were lured by the attractive returns offered per bushel by the ethanol processing plant, which in-turn affected the food prices that were dependent on corn as a basic ingredient.

In such a ‘multi-application crop’ feedstock situation, it would be worth taking a look at sweet sorghum. Sweet sorghum has been used for the production of edible syrup in the U.S. for over 100 years. The syrup is used as a sugar substitute in the food industry and research has shown that the crop has tremendous potential for ethanol production [16]. Sorghum production is concentrated in areas where the rainfall is insufficient and the temperatures are too high for profitable corn production. Most of the domestic sorghum acreage is in the southern Great Plains states with Texas, Kansas and Nebraska the leading producers. By the 1950s, about 90% of the acreage of sweet sorghum in the

United States was grown for forage [7]. However, some sweet sorghum has been grown for syrup and silage.

The climatic conditions in Oklahoma are favorable for sweet sorghum farming. As per USDA, ample moisture and high soil temperatures are favorable for good juice and stalk yield. The cultural practices are similar to corn. This crop can be adapted to the state of Oklahoma for ethanol production and secondary use as silage for cattlefeed.

1.1. Research Objectives

The state of Oklahoma has not been involved in the 'ethanol drive'. If we look at the present (July 2006) update on number and location of ethanol plants that are operational and under construction, it does not include the state of Oklahoma [13]. Considering the impact of an ethanol industry on a community's economic development and contribution towards U.S. national interests, it would be worth considering such a project. For such a project the most vital ingredient is the availability of biomass at the right time, right place and at lowest cost. Considering the environmental conditions and agricultural history throughout Oklahoma and growth habits of sweet sorghum, it appears as a promising crop as a feedstock for an ethanol project.

Sweet sorghum has a short harvest period from approximately August to October. At the end of the harvest, the sweet sorghum plant has the highest sugar yield measured in ^{0}Brix. (Sugar levels are given in ^{0}Brix, a unit, commonly used in the sugar industry, which represents the mass of sugar as a percentage of juice mass [16].) The goal is to harvest at the maximum level of ^{0}Brix for highest ethanol yield per ton of stalk yield. The specific objectives for this research include,

1. Evaluate the economic considerations and impact of introducing the sweet sorghum crop to the state of Oklahoma.
2. Represent and evaluate the ‘on-farm ethanol processing’ concept for the state of Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

2.1. Sweet sorghum

Sweet sorghum is often considered to be one of the most drought resistant agricultural crops as it has the capability of remaining dormant during the driest periods. Like other sorghum types, sweet sorghum probably originated in East Africa and spread to other African regions, Southern Asia, Europe, Australia and the U.S. Although a native to the tropics, sweet sorghum is well adapted to temperate climates. The plant grows to a height from 120 to over 400 cm [28].

Sweet sorghum production is concentrated in areas where the rainfall is insufficient and the temperatures are too high for profitable corn production. Thus most of the domestic sorghum acreage is in the southern Great Plains states, with Texas, Kansas and Nebraska the leading producers. However, some sweet sorghum has been grown for syrup or silage in Wisconsin and Minnesota [7]. The plant has been grown for edible syrup for more than 100 years in the U.S. More recently, it has been considered as a feedstock for ethanol production. Nathan (1978) stated that sweet sorghum has the greatest long range potential for ethanol production of the three main sugar crops (sugar cane, sweet sorghum and sugar beets) since it can be grown over a much larger geographic region than sugar cane. As mentioned earlier, sweet sorghum is a drought tolerant crop and hence capable of producing more carbohydrates per hectare than corn in this region [16]. Nuese and Gerald (1982), identified the important fact that sweet sorghum contains sugar instead of starch; the elementary processing stage of converting starch to sugar with enzymes is eliminated. They have formulated the idea of developing a harvester which would harvest the crop and extract the sweet sorghum juice on the farm [25].

In order to consider sweet sorghum as a feedstock for ethanol production, it is important to understand the growth habits and cultural practices for different varieties of sweet sorghum. These factors are directly associated with the cost of producing the sweet sorghum crop, harvest windows and harvesting costs, and energy requirements.

2.1.1 Sweet sorghum varieties

The examples of sweet sorghum varieties include Dale, Keller, M81-E, Theis, Topper, Sugardrip, Wiley, Sart, Tracy, Brandes, Honey, Georgia Blue Ribbon and Williams. As per USDA (United States Department of Agriculture), variety selection is one of the most important decisions in the production of sweet sorghum juice for ethanol conversion. Sweet sorghum varieties are quite different in their tolerance to drought or excessive water during the growing season. A good variety should yield stalks that are larger in diameter and vigorous enough to reach a good but not excessive height and to develop two or four tillers. Varieties that do no tiller freely usually produce low yields of stalks. A good variety should resist lodging. Lodging of stalks increases the cost of harvesting, which is a major expense in producing sweet sorghum juice. Lodging may be due to:

- Inherited weakness of the stalks that causes them to bend to a horizontal position before harvesting
- Severe disease infection that weakens the stalks by destroying their internal tissue; or
- Caving over of the entire plant, which may be influenced by varietal weakness of the root system, poor cultural practices, insect damage, or high wind during rainstorm [15].

For this research, it would be important to know about a few varieties, their requirements and maturity trends. Some background information on a variety would certainly help in planning the harvest to get the maximum return on the harvesting process. In the future, it may help to plan the harvest as per the variety maturity period allowing a group of farmers to share expensive equipment owned by a co-operative society.

The following are some of the popular varieties which are currently being evaluated in variety trials at several sites in Oklahoma.

Dale

Dale is an early maturing (115 days) variety with superior disease resistance compared to many older common varieties. Dale is a mid-season variety averaging about twelve feet in height at maturity. Panicle length is considered medium and generally is somewhat erect and compact. Dale is highly resistant to leaf anthracnose and stalk red rot which are major diseases of sweet sorghum.

Theis

Theis is a later maturing (130 day) variety which displays good resistance to lodging. The stalks are virtually free from the external waxy bloom common to many sweet sorghum varieties. Panicles are erect and semi-compact. Seed count for Theis averages about 21,000 per pound. Theis is highly resistant to leaf anthracnose and stalk red rot, both serious diseases in sorghum. It is tolerant to maize dwarf mosaic virus and moderately resistant to downy mildew. Theis is thought to be well adapted for the southeastern U.S. [18]

M81-E

M81-E is a later maturing (130 days) variety. Seed size averages about 24,000 per pound. The variety is well adapted for the southeastern U.S. The yield of juice from M81-E is generally superior to Dale. It appears to be more susceptible to light frost than the other varieties [18].

Topper

Topper 76-6 reaches maturity in about 120 days. Seed counts average about 20,000 per pound. Topper 76-6 is highly resistant to foliar anthracnose and has revealed good to intermediate resistance to grey leaf spot, zonate leaf spot, rough leaf spot, bacterial leaf stripe, and twisted top [18].

2.2. Soil Requirement

It should also be noted that in order to have a good crop, soil preparation is an important factor. The USDA handbook [15] on sorghum practices outlines very important and simple guidelines on soil requirements.

Many different soil surfaces are used for the production of sweet sorghum. In general, loam and sandy loam soils are best for the growth of sweet sorghum for juice. The field should have natural drainage, especially in localities that may have periods of heavy rainfall. Based on the soil tests and rainfall data available for a particular region, extra moisture during the growing period is also important for good yields of stalks and juice. Organic matter improves the water holding capacity of the soil. Heavy soils that warm slowly in spring are not suitable for sweet sorghum plantation. Sweet sorghum is one of the most sensitive crops to acid soils i.e. the soil pH should be greater than 5.8.

According to Zhang and McCray (2003), of 40,200 soil samples collected over the 77 counties in Oklahoma, 48.4% fell between the range 5.5-6.5 pH. Therefore soils in the state can support sorghum production enterprise [19].

2.3. Crop Rotation

Sweet sorghum usually fits in most of the crop rotation systems, especially cotton and corn. Because cotton is a clean cultivated crop, it usually leaves the land in a clean condition for sweet sorghum next year; few weeds will be present in the soil to interfere with young sweet sorghum plants.

Sweet sorghum may be grown successfully following a corn crop. The cornstalks should be thoroughly chopped and disked into the soil several weeks before sweet sorghum is planted [15]. Weed control is often needed with sweet sorghum following corn.

2.4. Fertilizer Application

It is not possible to recommend a single fertilizer practice to fit all farm conditions. The mixtures of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) should be applied in amounts that will supply approximately 40 pounds of N, and P_2O_5 {18 pounds of phosphorous (P)} and 30 to 40 pounds of K_2O {25 to 33 pounds of potassium (K)}. As per USDA, the yield of stripped stalk and syrup increases with an increase in nitrogen application [14].

2.5. Chemical Weed Control

A pre-emergence treatment with 2-choloro-4, 6-bis (isopropylamino)-s-triazine (porpazine) at the broadcast rate of 2.0 to 3.2 pounds per acre (active ingredient) will control many species of small seed annual weeds in sweet sorghum without injury to the crop in most situations. On light soils, a rate of 2 to 2.5 pounds per acre controls these weeds adequately, whereas higher rates would severely injure the crop.

CHAPTER III

THEORY AND PROCEDURES

3.1. Theory: Metrics for the sweet sorghum ethanol project

To evaluate the potential for the sweet sorghum enterprises in Oklahoma, efficiency, feasibility and economics play a vital role for positive returns. The terms can be elaborated as,

- Efficiency: Harvesting maximum acreage for ethanol production within a short harvest period with least cost inputs. This aspect would address efficient use of resources for the process. The harvester efficiency would be a constraint to the overall process since it would deliver the raw material for the ethanol conversion process.
- Feasibility: Sweet sorghum has a short harvest period of 2-3 months. During this period, the goal is to obtain the highest possible sugar level (^{0}Brix) over the harvest window. After obtaining the maximum maturity, the ^{0}Brix level of the plant starts dropping, which affects the ethanol conversion efficiency. To avoid such an effect, it is important to evaluate how much acreage can be harvested with highest possible sugar contents within the projected harvest time.

- Economics: Efficiency and feasibility are closely related to economics of the project. A balanced efficient and feasible process should be within economic constraints set forth by the project undertaker.

3.2. Procedure

3.2.1. On-farm ethanol production

Sweet sorghum can be processed using existing sugarcane technology, but the stalks must be transported to a central mill, and this would be expensive in an area where transportation is not efficient. Worley and Cundiff (1991) proposed a system analysis of sweet sorghum harvest for ethanol production. In their study, they analyzed three systems. In all three systems the sweet sorghum stalks were harvested with a harvester and pressed for juice with a different machine. The juice was then transported to a nearby distillation facility. The study considers the storage of sweet sorghum stalks. According to Worley and Cundiff, storing of sweet sorghum stalks enables the future juice availability as per the needs. The authors also emphasize the inability of the harvester maneuverability during rainy days [16]. It is important to note that the juice expression is not done with the harvester used for harvesting the sweet sorghum stalks.

The concept of on-farm ethanol production from sweet sorghum, "Sorganol", was conceived by Mr. Lee McClune, (President, Sorganol Production Co. Inc, Knoxville, IA., www.sorganol.com). The proposed ethanol production process involves harvesting and pressing the sweet sorghum stalks using a new mobile field harvester (patent pending) with a multi-roller press and juice collection unit mounted on the harvester. The harvester accomplishes both harvest and juice expression in a single pass through the field. The unit uses a standard forage chopper/header and feed rollers. After the stalks are pressed, they are expelled back onto the field. Juice is then pumped from the harvester directly into large storage bladders which are placed in the field, where fermentation takes place [31].

Considering the potential of "Sorganol", the important aspect of this project is to evaluate the 'on-farm ethanol processing from sweet sorghum'. Figure 1 shows the key components of the entire process. It is envisioned that the sweet sorghum would be harvested by a hypothetical harvester, a machine capable of both harvesting and squeezing sweet sorghum stalks and collecting juice. In-field storage and conversion of juice would be performed near the farm site. The vicinity of the distillation site is also an evaluation parameter since it would affect the economics and feasibility aspects of the process.

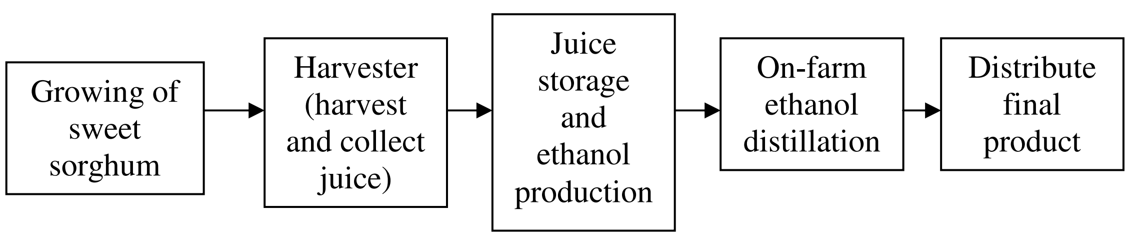

Figure 1: On-farm ethanol production from sweet sorghum

The economic evaluation of the 'on-farm ethanol processing from sweet sorghum' is a new concept and has not been practiced on a commercial basis. While evaluating such a new concept, it should be understood that most of the calculations and results are based on assumptions supported by logical reasoning, literature review, personal communication with professionals with expertise in farm machinery and crop processing, and information obtained through communication with private sector companies.

3.2.2. Project goal

The goal of this thesis is to evaluate on-farm ethanol processing on a commercial scale using sweet sorghum juice as a raw product. To understand the relationships between the inputs & outputs and how those affect the overall process, a 'cause-effect' diagram was developed (see figure 2). The 'cause-effect' diagram can be used to help list all the factors affecting the project at a glance. Each primary box (e.g.: Land, Labor, Transportation & Storage, Ethanol, etc.) represents a primary factor as a 'cause'. The secondary boxes (e.g.: Field speed, Harvesting, Total area harvested, Mobile distillation unit) are the factors affecting the primary causes. The objective is to measure the effect of these factors (primary and secondary) in terms of economy and efficiency on 'Sweet Sorghum Enterprise'.

The analysis of parameters, their values, the impact on efficiency of the entire process is evaluated with the spreadsheet and software packages. There are three main data entry and evaluation forms which serve as the foundation of the analysis.

- Parameter spreadsheet
- OSU Enterprise Budget software
- Harvester software

The 'Parameter spreadsheet' describes the range of values for different parameters for the project. It summarizes the assumptions made for the analysis.

To analyze the impact of all the factors on the sweet sorghum enterprise the ‘OSU Enterprise Budget software’ is used as one of the tools. Enterprise Budget software is spreadsheet based software designed to provide a planning and educational tool. The

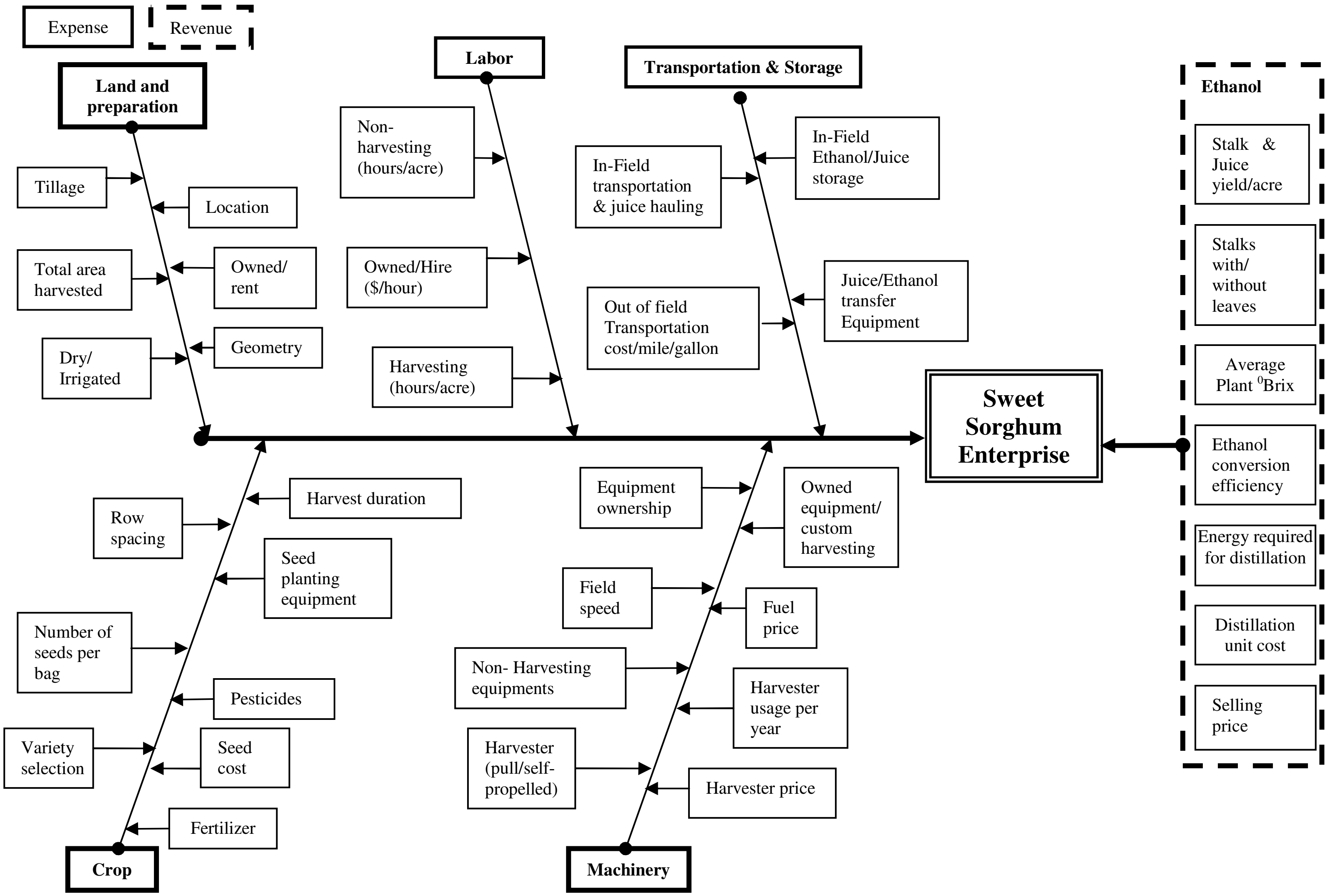

Figure 2: Modified expense and revenue diagram for sweet sorghum ethanol process

spreadsheet software tool was developed by Department of Agricultural Economics, Oklahoma State University. The technical support for this spreadsheet is provided by Mr. Roger V. Sahs, Extension Specialist. This spreadsheet incorporates historical data and specialist recommendations while allowing modification by the user. The application is designed to evaluate farming practices for the state of Oklahoma. The user can enter the values of total land harvested, fertilizer application rate and cost, pesticide selection and cost, machinery compliment size, seed cost, labor pay rate, interest rate, custom operations, and fuel value. More information on the OSU Enterprise Budget can be found at the OSU Enterprise Budget website [30]. The values obtained from the Enterprise Budget are used as part of the economic analysis of this research.

Harvester efficiency, ethanol conversion parameters, in-field transportation, storage facilities, and transportation costs are analyzed with a Microsoft Excel® based software entitled 'Harvester'. The values obtained from Enterprise Budget software and Harvester software, are combined to represent the results for evaluation and discussion.

As discussed earlier, feasibility of such a project is a vital metric. Feasibility assessment would address the acres harvested, average ^{0}Brix of the sorghum plant over the harvesting period, storage and hauling equipment capabilities, costing, ethanol yield over the harvesting period, and most importantly the harvester capabilities.

3.3. Data Mining

As mentioned previously, the sources of the data in the spreadsheets are personal communication with experts in the various fields, research articles, and communication with private sector companies. Each factor is an input to the Enterprise Budget and the Harvester spreadsheet. In this section, the source and method of data mining is explained. The data mining is the base for assumptions made throughout the project.

Land

Sweet sorghum is a drought tolerant crop. As of now, it is assumed that the land used is a 'dry land'(without irrigation). The area of the land under consideration would vary with the analysis of the harvester efficiency, ethanol yield and overall fixed & variable costs incurred. Based on the preliminary findings, the return on the investments made is greater with more land harvested. To avoid the problems in locating the in-field juice storing containers ("bladder") throughout the field, it is also assumed that the minimum length (one side) of the field is 660 feet (201.16 meter) [10]. The row spacing is a user input with the default value being 30 inches (0.025 meter).

Harvester

The hypothetical harvester is a combination of a harvesting and juice extraction mechanism. At this time, it is assumed that the harvester has a 2-row capacity, 175 engine horsepower, effective field speed of 3 miles/hour (4.82 kilometer/hour) and juice storage buffer of 4000 gallons (15,000 liters). The juice storage buffer would provide a time buffer for the in-field juice hauling operations. The cost of a new hypothetical harvester is $60,000, $90,000 and $120,000 with a useful life of 15 years. The hypothetical harvester is assumed to be owned equipment by the entity which would undertake such a venture. Based on the Enterprise Budget parameters, the complimentary machinery size would vary as per the acres harvested and equipment requirement assumptions made for the budget. The Enterprise Budget does allow the user to select the horse power for the harvester. The selection of 'machinery complement size' affects the number of tractors available for other operations. For this research, a medium and high complement size was chosen based on the number of acres covered during the harvest period, which makes 270 hp, 160 hp and a 90 hp tractor available depending on the complementary size selection [10] [14].

Sweet sorghum silage

The pressed sweet sorghum stalks can be used as animal feed. The silage can be a possible revenue item. At this time there is not substantial data available to present an analysis. The dry matter yield could be 65% of the wet matter yield; for example if wet matter yield is 20 tons/acre then dry matter yield would be 13 tons/acre. While considering silage revenue, one should evaluate the processing cost of the silage [10].

Sweet sorghum seed

As per National Sweet Sorghum Producers and Processors Association (NSSPPA), the price of sorghum seed is $6/pound ($13 per kg). The seed size does vary regardless of variety. On an average there are 1000-2000 seeds/pound (approximately 2200-4400 seeds/kg) [7]. For this research, seed cost is considered in terms of 'per bag', and price range is $30 to $40.

Fertilizer

Fertilizer application improves the stalk yield. At the same time, the cost parameter should be analyzed. For this project, a blend of 20-20-20 of N, P_2O_5, and K_2O is used. The application would provide 40 pounds (18.14 Kilograms) of each per acre. The cost of such a fertilizer varies as per the application quantity and blend proportion. It is assumed the fertilizer application is a custom work and the rate is $5.82 per acre [14].

Pesticide

The pesticide application is assumed to be comparable to that used in production of corn. The Enterprise Budget has specified pesticide 'Dual' and 'Aim' for use. The Dual application quantity is 1.5 pints/acre (1.75 liter/hectare) and, on an average, priced at $13.25 per pint ($28.19 per liter). The 'Aim' application quantity is 0.33 ounces/acre (0.024 liters/hectare) and, on an average priced at $5.61 per ounce ($193.45 per liter). It is assumed that the pesticide application is custom work and the rate is $3.72 per acre [20].

Labor

The labor rate and usage is a sensitive parameter. Varying the labor usage and rate would make the difference on the net returns to the project. The allocation of labor requirement is different for Enterprise budget software and the Harvester software. To analyze the sensitivity of the budget labor rate per hour has been varied with different scenarios. For this research the labor rate range is $8 to $12 per hour.

Storage

As the harvester works through the field it is envisioned that a juice extracting mechanism would constantly press the harvested stalks and collect the juice. At this point, it is assumed that the harvester has a 4000-gallon (15,000-liter) juice storage capacity. To collect the juice from the harvester and transport it to a main storage location, multiple hauling tanks would be used. For this research based on the information gathered, a 4000-gallon in-field hauling tank capacity is suitable. These tanks would be moved by tractor used for 'in-field' transportation purposes. Multiple main storage tanks ("bladder") would be used to collect the juice from in-field hauling tankers. The placement and number of bladders would be justified by the fermentation duration, desired ethanol percentage in the beer, juice yield, field geometry and number of infield juice hauling tanks available.

The in-field harvester efficiency and in-field juice hauling tank capacity are the constraints over "juice buffer storage" of the harvester. While considering the storage buffer on the harvester, its impact on field efficiency should be evaluated.

Initial investment in the juice storage bladders is an important point in considering such a project. Based on the current market price, a 20,000-gallon (76,000-liter) capacity fuel bladder is ranged from $10,000 to $15,000. The price of an equipped 4000-gallon in-field juice hauling container (attached to a tractor) is estimated to cost between $32,000 and $36,000 [10].

Distillation

The distillation unit investment is an important one as the cost of distillation represents a major portion of total costs incurred. This cost would include actual distillation equipment cost, labor, and energy cost.

The distillation unit is assumed to be powered by natural gas though it would be possible to use the bagasse from sweet sorghum as a fuel for the distillation unit and other energy needs [27]. For this research, it is assumed that an ethanol distillation unit with a distillation capacity of 1,200,000 gallon/year is used. Such a distillation unit is priced at $200,000 [10]. This cost can also be expressed as $0.17 per gallon of ethanol distilled. While considering the distillation cost for different land sizes and parameter levels, ethanol yield over the harvest is multiplied by the distillation unit cost per gallon (in this case it is 0.17 $/gallon). The cost of distillation is spread over total acres of land harvested. The distillation unit is assumed to be running 24 hours a day 350 days a year [10]. To administer, operate and maintain the distillation unit five full-time personnel are hired at $12 per hour remuneration.

Based on the work of Hubbard et.al [22], the steam energy required per acre for distillation purposes is based on the alcohol percentage in the beer used as the raw material. The distillation would use approximately 15 lbs to 19 lbs (6.8 kg to 8.6 kg) of steam per gallon of ethanol. For this research, based on the acres harvested, sweet sorghum stalk yield and ethanol conversion parameters assumed, the energy required for that steam generation ranges from 18,600 Btu to 29,800 Btu per gallon of ethanol. Another 3,323 Btu is used for the electricity purposes [22]. The energy input is then distributed over the area harvested. The ethanol distillation unit is depreciated over 5 years [10].

CHAPTER IV

RESULTS AND DISCUSSION

The on-farm ethanol production from sweet sorghum juice is evaluated based on two main constraints: harvester efficiency in terms of total acres harvested and average ethanol yield during the harvest period. To evaluate these two main constraints, a set of parameters was developed. These parameters were evaluated with the Enterprise Budget and Harvester software. Each parameter has a low, medium and high value. To evaluate the effect of parameters on different land acres, each selected acreage, i.e. 500, 1000 and 1500, is analyzed with worst, medium and best case scenarios.

As seen from Table 1, worst, moderate and best scenarios reflect three different sets of values for each item. The 'worst' considers those values for all the items resulting in the highest fixed cost, operating cost, low revenue and low returns to the investment. The 'moderate' would includes those values that would be considered mid-range. The 'best' reflects the more optimistic, yet achievable, values for all the items. The low values for items results in low fixed cost, operating cost, high revenue and high returns to the investment. This research follows a pattern of 'low cost, high revenue' and 'high cost, low revenue'.

4.3. Parameters and their importance

The parameters can be categorized as primary and secondary based on their impact on the returns above all costs based on the cost comparisons in Tables 2, 3, 4 and 5. While categorizing these factors as primary and secondary, the degree of control should be evaluated.

Land

Land is a primary factor under consideration. The land is divided into three levels based on acreage i.e. 500, 1000 and 1500. For this research, it is possible for a single producer to harvest 500 acres based on the time constraint, harvest duration and average ethanol yield over the harvest duration assumptions made. However looking at Table 5, the return on investment is not lucrative when compared with higher acreages. In order to harvest higher acreage, it would be thoughtful to consider a cooperative effort. As seen from the 'best', 1500 acres values, the fixed expenses as well as operating expenses are spread over a higher acreage reducing the cost per acre.

Sweet sorghum and ethanol

The parameters considered for sweet sorghum tonnage yield and ethanol conversion factors in Table 1 are of vital importance since the selection of those factors decide the ethanol yield per acre. The only revenue item for this research is the sale of ethanol. The sweet sorghum tonnage yield data [10] should be carefully evaluated as it is one of the important factors in the ethanol yield per acre calculations.

4.1. Parameters

Parameter	Scenarios		
	Worst	**Moderate**	**Best**
Tillage	Low-till Rotation		
Machinery compliment size	Medium	High	High
Working hours in a day	10		
Harvester width (inches)	60		
Harvester field speed (miles/hour)	4		
Effective harvester field speed with 75% efficiency (miles/hour)	3		
Loan period (years)	15		
Harvester cost ($/unit)	$120,000	$90,000	$60,000
Rows spacing (inches)	30		
Main storage bladder cost (20,000 gallons)	$15,000	$12,500	$10,000
In-field juice hauling container (4,000 gallons)	$36,000	$34,000	$32,000
Fertilizer ($/ton)	386.40	368.00	349.60
Fertilizer application rate ($/acre)	5.82		
Pesticide ($/acre)	19.80	18.86	17.92
Pesticide application labor rate ($/acre)	3.72		
Seed ($/bag) (bag weight approximately 5 lbs)	40.00	35.00	30.00
Fuel ($/gallon)	2.50	2.40	2.30
Labor ($/hour)	12.00	10.00	8.00
Interest rate (%)	9	8	7
Transportation cost for juice/ethanol from field to a centralized processing site ($/mile/gallon)	0.07	0.06	0.05
One-way loaded miles for transportation cost	100	80	60
ETHANOL			
Crop yield (ton/acre)(wet matter)	20	27.5	35
Juice expression ration (lb/lb of Biomass)	0.45	0.55	0.65
^{0}Brix level (% of sugar)	14	16	18
Ethanol conversion efficiency (%)	85	90	95
Ethanol revenue ($/gallon)	1.50	1.75	2.00

Table 1: Parameters used to compare three base scenarios: worst, moderate and best

4.2. Cost and revenue comparisons from land preparation through sale of ethanol

Item	Worst	Moderate	Best
	COST		
Sweet sorghum seed ($/acre)	10.00	8.75	7.50
Fertilizer ($/acre)	36.80	36.80	34.96
Pesticide ($/acre)	22.81	21.73	20.64
Annual Operating Capital ($/acre)	6.50	5.47	4.51
Custom hire cost (fertilizer and pesticide operations) ($/acre)	13.26	13.26	13.26
Machinery labor ($/acre)	10.68	8.90	7.12
Machinery, fuel, lube and repairs ($/acre)	23.18	22.57	21.97
Machinery and irrigation ($/acre)			
Interest	16.92	15.04	13.16
Taxes (@ 1.00%)	2.85	2.85	2.85
Insurance (0.60%)	1.13	1.13	1.13
Depreciation	19.47	19.47	19.47
In-field transportation ($/acre)	14.93	14.93	14.93
Outbound transportation cost ($/acre)	5.04	9.72	13.50
Juice storage cost ($/acre)	34.53	40.87	44.37
Ethanol distillation cost ($/acre)	70.66	99.44	134.26
TOTAL COST ($/acre)	290.56	320.93	353.63
REVENUE			
Ethanol production (gallon/acre)	75	153	272
Ethanol ($/acre)	112.50	267.75	544.00
RETURNS ABOVE ALL SPECIFIED COSTS ($/acre)	-178.06	-53.18	190.37

Table 2: Cost and revenue comparisons (500 acres)

Item	Worst	Moderate	Best
		COST	
Sweet sorghum seed ($/acre)	10.00	8.75	7.50
Fertilizer ($/acre)	38.60	36.80	34.96
Pesticide ($/acre)	22.81	21.73	20.64
Annual Operating Capital ($/acre)	6.43	5.42	4.48
Custom hire cost (fertilizer and pesticide operations) ($/acre)	8.88	13.26	13.26
Machinery labor ($/acre)	13.26	8.90	7.12
Machinery, fuel, lube and repairs ($/acre)	23.68	23.09	22.50
Machinery and irrigation ($/acre)			
Interest	9.39	8.35	7.30
Taxes (@ 1.00%)	1.58	1.58	1.58
Insurance (0.60%)	0.63	0.63	0.63
Depreciation	10.81	10.81	10.81
In-field transportation ($/acre)	12.57	12.57	12.57
Outbound transportation cost ($/acre)	5.04	9.18	13.50
Juice storage cost ($/acre)	17.26	20.43	22.18
Ethanol distillation cost ($/acre)	65.86	94.64	129.46
TOTAL COST ($/acre)	279.90	302.42	332.42
REVENUE			
Ethanol production (gallon/acre)	75	153	272
Ethanol ($/acre)	112.50	267.75	544.00
RETURNS ABOVE ALL SPECIFIED COSTS ($/acre)	-134.30	-6.89	236.71

Table 3: Cost and revenue comparisons (1000 acres)

Item	Worst	Moderate	Best
		COST	
Sweet sorghum seed ($/acre)	10.00	8.75	7.50
Fertilizer ($/acre)	38.60	36.80	34.96
Pesticide ($/acre)	22.81	21.73	20.64
Annual Operating Capital ($/acre)	6.43	5.42	4.48
Custom hire cost (fertilizer and pesticide operations) ($/acre)	13.26	13.26	13.26
Machinery labor ($/acre)	8.88	7.40	5.92
Machinery, fuel, lube and repairs ($/acre)	23.68	23.09	22.50
Machinery and irrigation ($/acre)			
Interest	9.39	8.35	7.30
Taxes (@ 1.00%)	1.58	1.58	1.58
Insurance (0.60%)	0.63	0.63	0.63
Depreciation	10.81	10.81	10.81
In-field transportation ($/acre)	11.78	11.78	11.78
Outbound transportation cost ($/acre)	5.46	9.36	13.50
Juice storage cost ($/acre)	11.51	13.26	14.79
Ethanol distillation cost ($/acre)	64.26	93.04	127.86
TOTAL OPERATING COST ($/acre)	205.16	230.63	262.39
TOTAL FIXED COST ($/acre)	33.92	34.63	35.11
FIXED + OPERATING COST ($/acre)	239.08	265.26	297.50
REVENUE			
Ethanol production (gallon/acre)	75	153	272
Ethanol ($/acre)	112.50	267.75	544.00
RETURNS ABOVE ALL SPECIFIED COSTS ($/acre)	-126.58	2.49	246.50

Table 4: Cost and revenue comparisons (1500 acres)

The analysis reveal following 'Returns above all specified cost' (Net profit),

Returns above all specified costs comparison ($/acre)			
Acres	Worst	Moderate	Best
500	-178.06	-53.18	190.37
1000	-134.30	-6.89	236.71
1500	-126.58	2.49	246.50

Table 5: Returns above all specified costs comparisons

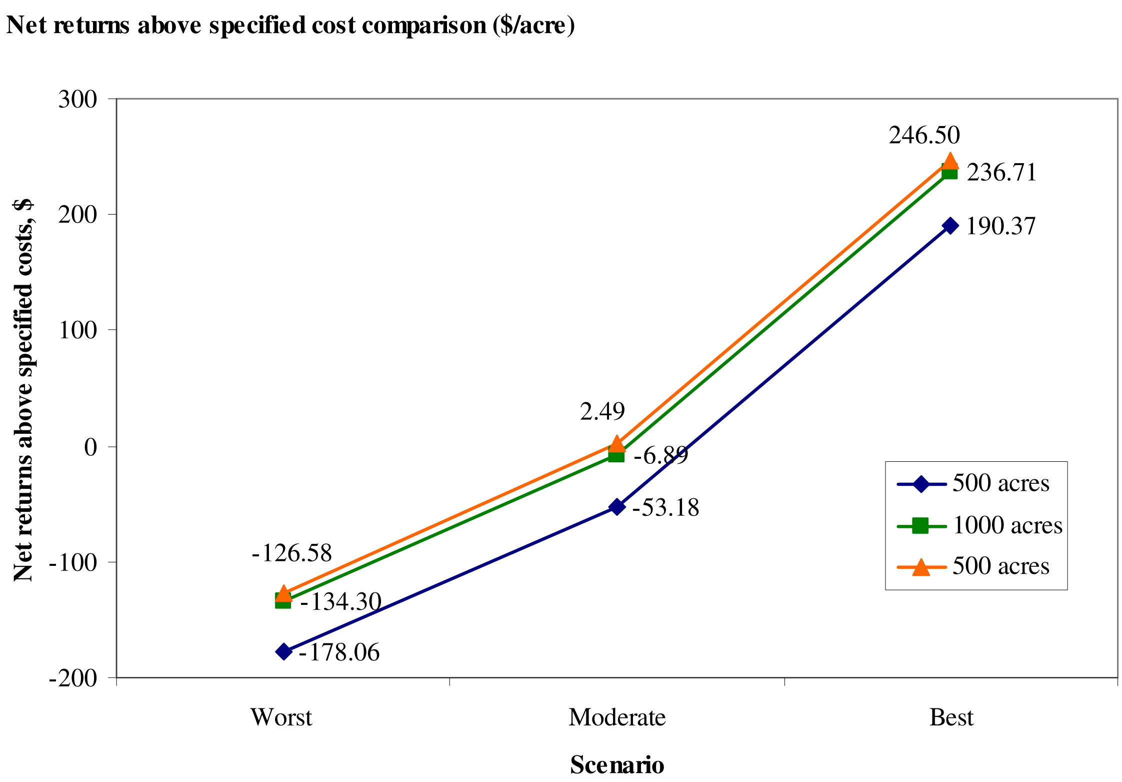

Figure 3: Comparison of net returns above all specified costs

Harvester

For this research purpose, a harvester is envisioned which is capable of following the operations,

- Harvest sweet sorghum.
- Press sweet sorghum stalks and collect juice in a temporary tank storage.
- A 4000-gallons capacity tank is assumed.

Since a harvester is the most important piece of processing equipment, it should be considered as a primary factor. It is also assumed that the harvester requires a 175 hp tractor and is a ‘pull’ type. At this point, it is assumed that the harvester is within a price range of $60,000 and $120,000. The life of such a harvester is 2500 hours [17]. While considering the harvest period it is important to take into consideration the life and capability of the harvester. For this research, the harvest period analyzed is based on the number of acres harvested. Based on the assumptions made for harvester working hours in a day, effective field speed and row spacing for 500, 1000 and 1500 acres of land, it take approximately 29, 58 and 86 days respectively to complete the harvest. The hours of harvester usage ranges from 288 to 863 hours per year. It is also assumed that the harvester capability is 960 hours (96 actual working days, 10 hours a day). While considering the number of harvester machines required based on the harvester capability, it is assumed that the harvester machine and tractor undergo standard repairs and lubrication schedule. In practice, this harvester life could be increased through effective use of the machinery and maintenance schedule. Increasing the harvester life would yield higher return to the investment through savings on fixed cost as well as operating expenses.

Enterprise Budget software has fixed ratios for repairs and maintenance costs. As seen from the cost comparison in Table 6, the fixed cost is not substantially reduced when 1500 acres of land is harvested compared with 1000 acres. A similar trend is observed with operating expenses. This is a limitation of Enterprise Budget software [14]. The efficiency of the harvester has a major impact on the investment in sweet sorghum juice storage. Based on the field geometry, number of in-field juice hauling containers, traveling speed of juice hauling containers and acres covered by the harvester per refill, the location of the main storage bladders (containers) in the field are determined.

Fixed cost comparison ($/acre)			
Acres	Worst	Moderate	Best
500	74.90	79.36	80.98
1000	39.67	41.80	42.50
1500	33.92	34.63	35.11
Operating cost comparison ($/acre)			
Acres	Worst	Moderate	Best
500	215.66	241.57	272.65
1000	207.13	232.84	264.79
1500	205.16	230.63	262.39

Table 6: Total Fixed and Operating cost comparisons of harvest operation

In-field transportation tractor and container

Considering the values from Table 7, if a farmer decides to invest in two in-field juice hauling containers, the main storage containers could be placed within approximately 19,200 feet of the harvester. It is important to understand that the value depends on factors like traveling speed and field geometry. More in-field juice hauling containers would reduce the distance between main storage and harvester, but at the same time would add to the investment required.

Volume of juice hauling container (gallon)	4000
Unloading rate (gallon/minute)	1300
Unloading time for container (minute)	4
Additional time taken (minute)	10
Hauling speed for the container (juice loaded) (mile/hour)	5
Return speed for the container (empty) (mile/hour)	8
Effective harvester speed (mile/hour)	3
Volume of main storage container (gallon)	20,000
Area covered per refill (acre)	0.8

Table 7: In-field transportation parameters

While evaluating the degree of control in reference to the harvester, the fundamental consideration would be the purchase price of the harvester, field speed, and tractor hp. The tractor which would pull this machine should be capable of moving efficiently through the field in all working conditions. Any compromise or difficulties posed by the tractor would be a bottleneck to the entire operation and its efficiency. It should also be noted that the area covered per refill primarily depends on the juice buffer size of the harvester machine.

Special containers are required for hauling the sweet sorghum juice from the harvester to the main storage container. These in-field containers have custom accessories for unloading. The quantity of containers depends on the harvester buffer size and efficiency of the in-field transportation. The decision as to the number of containers depends on field geometry, harvester juice buffer size, maneuverability with available tractor and the finance available. The containers are a "pull type" and for this research, it is assumed that a 75 hp tractor is the conveyance. The cost of such tractor operation is \$17.75 per hour of usage [21]. It is assumed that it is a newly purchased tractor at \$40,000 [20]. In the Harvester software, the user can enter the cost, tax rate, salvage value and years of usage and analyze accordingly. It is critical to make an assessment of tractor life and total process duration. If a tractor is not capable of functioning effectively when required, the farmer must buy a new tractor or make a tractor available which can be dedicated to this operation. This consideration would change the operating cost.

Juice storage and transportation

Juice storage is a primary factor under consideration since it involves logistical as well as financial decisions. The in-field juice hauling containers empty into the main storage 'bladders' which are located as per the harvester field efficiency, in-field tractor operation efficiency and field layout. For this research, it is assumed that the capacity of the container is 20,000 gallons (75,700 liters). It is critical to analyze and make a sound decision while investing in such a large capacity container. For this research, it is assumed that the fermentation period is five days. The main containers would be emptied every five days based on the inspection of juice characteristics. Since it is difficult to relocate these containers, it is suggested that a farmer make a primary plan of field layout and possible locations for container placement. Container relocation may add an extra operating expense to the overall project which subsequently would reduce net operating profit.

Once the juice is stored in main storage containers, the process of fermentation is initiated. Through partial fermentation the producer can determine the ethanol percentage in the beer. For outbound transportation of completely processed ethanol, it is assumed that a 9000-gallon (34,000-liters) tanker (18-wheeler) would transport the load to a desired destination. This operation could be done by a third party transportation vendor. The cost is based on miles traveled, plus charge per mile, and per gallon transportation charge. Even though the per mile per gallon charge for transportation is low, the logistical issue is of vital concern. The frequency of tanker operation would determine the overall transportation cost as well as the initial investment in main storage containers.

Ethanol distillation

Ethanol distillation is one of the most important steps of this project. At this time, there is no data available to make a sound decision on the equipment cost and actual distillation energy requirements. The cost figures presented in Table 8 are based on assumptions, author's logical reasoning and work from Hubbard et.al. [22].

Acres	Worst		Moderate		Best	
	$/acre	% of Total cost	$/acre	% of Total cost	$/acre	% of Total cost
500	70.66	24	99.44	31	134.26	38
1000	65.86	27	94.64	34	129.46	42
1500	64.26	27	93.04	35	127.86	43

Table 8: Distillation cost comparisons

It should also be noted, the distillation cost is directly proportional to the juice quantity and inversely proportional to the ethanol concentration in the beer. The investment in distillation is conceivably within the scope of a large producer or a cooperative. An in-depth analysis of distillation cost through measured natural gas usage would provide a better understanding of the analysis.

CHAPTER V

CONCLUSIONS

Sweet sorghum is a potential feed stock for ethanol production. Due to the recent U.S. national interest in renewable energy, ethanol has gained notable attention. In Oklahoma, sweet sorghum can be grown successfully considering its growth habits and preferred soil and climatic conditions. Since sweet sorghum has a limited harvest period, it would be important to investigate the infrastructure requirement, land requirement and finance required for such a venture. This research was undertaken to evaluate economic feasibility of 'on-farm ethanol production from sweet sorghum'.

The theoretical process would produce a sweet sorghum crop on farm, a hypothetical harvester would harvest and squeeze the crop, containers would allow the fermentation process plus store the juice, and an ethanol distillation unit would finish the process. As a starting point, 500, 1000, and 1500 land acreages were selected and different parameters were evaluated based on low, medium and high values. 'OSU Enterprise Budget' software and the author developed a spreadsheet based 'Harvester software' to be used for this evaluation. Based on the analysis provided, it can be concluded that, The development of an efficient harvester machine capable of performing variety of tasks is also a key to the project. Successful development of a harvester machine at a competitive price would yield a higher return to the investment.The development of an efficient harvester machine capable of performing a variety of tasks is also a key to the project.

- Successful development of a harvester machine at a competitive price would yield a higher return to the investment.
- Sweet sorghum can be successfully grown in most parts of Oklahoma. Soil and dry climatic conditions in Oklahoma are favorable for this crop.
- The scenarios developed provide insights on the potential economic feasibility of on-farm ethanol production using sweet sorghum.
- Returns on the investment is higher with higher land acreage.
- Ethanol distillation cost is a major portion of total cost of the project.

CHAPTER VI

RECOMMENDATIONS

5.1. Recommendations

Field data

As for any project, the more data available, the better the probability of justifiable results. For this project, field data on following factors would help in making more sound decisions,

- Sweet sorghum plant yield per acre
- Juice expression capacity
- Sweet sorghum varieties and their maturity period
- Ethanol conversion efficiency experiments
- Actual field time study
- Correlation between a varieties maturity period and ^{0}Brix levels of the plant.

The correlation between variety maturity and ^{0}Brix, would increase the harvest duration. An increase in harvest duration would yield higher returns on the investment.

Process Simulation

One of the most important initiatives for this research would be to conduct a simulation using a software package like 'Arena'. It would be helpful to layout the project and analyze through statistical tools with actual field data. The factors identified in this project would help in making this simulation study more realistic.

Ethanol distillation

Ethanol distillation is the revenue factor for this project. It should take into consideration the 'mobility' of the unit as the concept of 'on-farm ethanol production' is under review. For this research, the energy used for distillation is assumed to be natural gas. The distillation unit should be capable of utilizing sweet sorghum pressed stalks as an energy input. This approach would certainly make the process more environmentally friendly as well as economical.

It is vital to consider the 'dynamics' of the distillation process. The word 'dynamics' considers the operating length of the distillation process, employee requirement over a period of time, sufficient input for distillation, logistical synchronization with main storage of final product and outbound transportation system. For analyzing the 'dynamics', the author reiterates the importance of a simulation study.

REFERENCES

1. Allen, M. (May 2006). *Crunching The Numbers on Alternative Fuels*. Retrieved June 2006, from http://www.popularmechanics.com/science/earth/2690341.html

2. American Coalition for Ethanol (2006). *ACE Ethanol Handbook* Retrieved August 2006, from http://ethanol.org/EthanolHandbook2006.pdf.pdf

3. Bitzer, M. J. *Production of Sweet Sorghum for Syrup in Kentucky*. Cooperative Extension Service.

4. Butterfield, F. (1981). *Farm-scale ethanol fuel production plant*. From http://journeytoforever.org/biofuel_library/Butterfield/butterfield1.html

5. Cundiff, J. S. (1990). *Potential for Sugar Cane/Sweet Sorghum as a feed stock for Energy Systems.* Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

6. Diver, S. (March 2003, April 2006). *Sorghum Syrup*. From http://ww2.attra.ncat.org/where.php/PDF/sorghumsyrup.pdf

7. Undersandler, D.J., Lueschcen, W. E., Smith, L.H., Kaminski, A.R., Doll, J.D., Kelling, K.A., and Oplinger, E.S. (November 1990). *Sorghum-For Syrup*. Alternative Field Crops Manual.

8. *Fuel From Farms, A Guide to Small Scale Ethanol Production*. (1980).). Oak Ridge, Tennessee: Technical Information Center.

9. Hobbs, J. C. (2006). Ponca City. Personal communication

10. Huhnke, R. L. (2006). Stillwater, Oklahoma. Personal communication

11. National Renewable Energy Laboratory, (April 1999). *Ethanol: Separating Fact from Fiction* (Publication. Retrieved Aug 29, 2006, from Department of Energy: http://www.eere.energy.gov/afdc/pdfs/factfict.pdf)

12. Mask, P.L., Morris, W.C. (Nov 1991). *Sweet Sorghum Culture and Syrup Production*. University of Tennessee.

13. Renewable Fuels Association (2006). *From Niche to Nation: Ethanol Industry Outlook 2006.* Retrieved June 2006, from http://www.ethanolrfa.org/objects/pdf/outlook/outlook_2006.pdf

14. Sahs, R. V. (2006). Stillwater, Oklahoma. Personal communication

15. Shough, B. (1973). *Culture of Sweet Sorghum for Sirup Production*. Agricultural Handbook No.441

16. Worley J. W., Cundiff J. S.(1990). *System Analysis Of Sweet Sorghum Harvest For Ethanol Production In The Piedmont*. American Society of Agricultural Engineers, *34* (2), 539-547.

17. Farm Machinery Management Committee (1998). *Agricultural Machinery Management Data*; Power and Machinery Division Standards Committee, ASAE, D497; pp 364-365.

18. Mississippi State University Extesnsion Service, *Crops: Sorghum*. Retrieved October 11, 2006, from http://msucares.com/crops/sorghum/descriptions.html

19. Zhang, H., McCray, B. (2003). *Oklahoma Agriculture Soil Test Summary 2000-2003* (No. CR2253). Stillwater: Department of Plant and Soil Sciences, Oklahoma State University. Oklahoma Cooperative Extension Service

20. Doye, D., Sahs, R., Kletke, D. (2004). *Oklahoma Farm and Ranch Custom Rates 2003-2004* (Current Report No. CR205). Stillwater: Oklahoma State University.

21. Lazarus, W., Selley, R. (2005). *Farm Machinery Economic Cost Estimates for Late 2005*; pp 6-7; University of Minnesota Extension; URL: http://www.extension.umn.edu/distribution/businessmanagement/DF6696.pdf

22. Hubbard, S. (2006). *The production of ethanol from sweet sorghum: An investigation into the net energy balance*. Unpublished data; New Product Development Center, Oklahoma State University.

23. Energy Information Administration. *Natural Gas Monthly [Monthly Report of Natural Gas Purchases and Deliveries to Consumers* (No. EIA-857) and *Monthly Natural Gas Marketer Survey* (No. EIA-910)]. December 2006. Accessed: January 2007

24. Bellmer, D. (2006). *Unpublished field experiments data*. December 2006

25. Nuese, G. A., Hunt, D. R. (1983). *Field harvest of sweet sorghum juice*. Transactions of the ASAE, 26, pp 656-660

26. U.S. Environmental Protection Agency (EPA), (March 2006). *MTBE in fuels* Retrieved Accessed January 14, 2007, from Environmental Protection Agency: http://www.epa.gov/mtbe/gas.htm

27. Rajvanshi, A.K., Nimbkar, N. (September 2001). *Sweet Sorghum R&D at Nimbkar Agricultural Research Institute*. Nimbkar Agricultural Research Institute (NARI). Phaltan, Maharashtra, India.

28. Gnansounou E., Duriant A., and Wyman C.E. (November 2004). *Refining sweet sorghum to ethanol and sugar: economic trade-offs in the context of North China.* Bioresource Technology, 96 (9), pages 985-1002.

29. Renewable Fuels Association (2006). http://www.ethanolrfa.org/resource/facts/

30. OSU Enterprise Budget (2006). http://www.agecon.okstate.edu/budgets/contact.asp

31. Kundiyana, D. 2006. "*Sorganol®": In-field production of ethanol from sweet sorghum"*. M.S. Thesis, Oklahoma State University, Stillwater, Oklahoma.

APPENDIX

Appendix A

The following table shows the ^{0}Brix data collected from Oklahoma Experiment Research Stations. This is an unpublished data by Dr. Danielle Bellmer, Department of Food Agricultural Product Center, Oklahoma State University.

Fort Cobb

Date	Dale	M81-E	Theis	Topper
September 5, 2006	17.4	12.8	12.3	16.6
September 12, 2006	17.1	15.2	13.3	16.3
September 19, 2006	19.8	14.0	15.4	19.5
September 27, 2006	17.5	16.8	16.6	19.2
October 3, 2006	18.5	17.3	17.1	17.8
October 10, 2006	15.7	14.7	16.5	18.9
October 17, 2006	17.2	13.8	15.8	18.3
October 24, 2006	14.2	19.5	15.8	19.3

Haskell

Date	Dale	M81-E	Theis	Topper
October 4, 2006	16.8	19.2	19.2	16.0
October 11, 2006	16.3	19.9	19.3	16.7
October 18, 2006	15.5	15.1	15.5	13.8
October 25, 2006	15.3	15.3	11.7	15.3
November 1, 2006	13.4	15.3	17.2	15.8

Appendix B

Below is the screen shot showing a part of the Harvester software. This module allows a user to enter the information about land, time and field layout. The logical values are shown under the column ‘Range’, which are simply guidelines to the user. The cells marked in ‘Yellow’ color are input while green cells are the output values.

LAND		Range
Acres to harvest	1500	Minimum 100
TIME		**Range**
Working hours in a day (hours)	10	8 To 24
Harvester working days	***86***	
Acres harvested in a day	***17.4***	
Total hours of work (hours)	***862.5***	
Harvester working capability		
FIELD LAYOUT		**Range**
Approximate length of one side of the field (feet)	660	
Row spacing (inches)	30	20 To 48

HARVESTER		Range
Harvester field speed (miles/hour)	4	1 To 10
Harvester efficiency (%)	75%	75 To 85
Width of the harvester (inches)	60	Minimum 60
Harvester alignment time (minutes)	2	2 To 10
Daily harvester working duration (hours)	10	1 To 24
Harvest duration (days)	120	60 to 150
Percent of days available for harvesting operations (%)	80%	50 to 100
Theoretical harvester working days	***96***	
Harvester working capabilities (hours)	***960***	

Below is the screen shot of Harvester software showing a module which allows a user to enter the values and information about in-field storage, containers and in-field transportation arrangements.

IN-FIELD JUICE HAULING CONTAINER		Range
Volume of In-field juice hauling container (gallons)	4000	500 To 10,000
Hauling speed for the container (miles/hour)	5	3 To 8
Unloading rate (gallons/minute)	1300	1300 To 1500
Additional time required for In-field hauling container to unload sweet sorghum juice (minute)	10	1 To 20
Return speed for the empty container (miles/hour)	8	5 To 15
Number of in-field juice hauling containers	2	
In-field transportation container price	$32,000	$20,000 To $40,000
In-field transportation container salvage value	$10,000	$1000 To $5000
In-field juice hauling container investment	***$64,640***	
Maximum allowable distance of Main Juice storage from harvester (feet)	***11,461***	

IN-FIELD TRANSPORTATION TRACTOR		Range
Cost of tractor operation ($/hour)	$17.75	$15.00 To $20.00
New tractor purchase price	$40,000	$30,000 To $60,000
Salvage value	$5,000	$5,000 To 15,000
Ownership duration (years)	15	10 To 20
Cost of tractor operation ($/acre)	***$11.78***	

IN-FIELD SWEET SORGHUM MAIN JUICE STORAGE		Range
In-field juice storage container capacity (gallon)	20,000	20,000 To 50,000
In-field juice storage container price	$10,000	10,000 To 20,000
In-field juice storage container salvage value	$1,000	0 To 1,500
Number of In-field juice storage containers	***24***	
Number of additional ethanol storage containers	2	
Total in-field juice storage container investment	***$237,833.04***	
Total storage and in-field transportation investment	***$302,473.04***	
Storage cost ($/acre)	***$14.79***	

Below is the screen shot of a module from the Harvester software showing sweet sorghum production, ethanol conversion parameters, finance and distillation parameters. The range values are for guidance purposes.

SWEET SORGHUM JUICE		Range
Sorghum yield (ton/acre)	35	20 To 30
Juice expression ration (lb/lb biomass)	0.65	0.45 To 0.65
Refractomerter reading (soluble solids in juice)	18%	14 To 18
Theoretical soluble sugar in the juice (%)	90%	Maximum 100
Juice Density (lb/gallon)	9.183	
Sugar content of the juice (%)	***16%***	
Total sweet sorghum juice collection (gallon)	***7,434,000***	
Sweet sorghum juice collection per day (gallon)	***86,191***	

ETHANOL		Range
Ethanol yield (conversion efficiency)	95%	85 To 95
Density of ethanol (lb/gallon)	6.582	
Ethanol yield (gallon/acre)	***272***	
Ethanol yield per day (gallon)	***4,730***	
Total ethanol yield (gallon)	***408,000***	

FINANCE		Range
Loan amount	***$302,473.04***	
Loan period	15	10 To 20
Sales tax rate (%)	1%	
Interest rate	7%	7 To 9

ETHANOL DISTILLATION UNIT		Range
Ethanol distillation capacity (gallon/year)	1,200,000	
Distillation equipment life (years)	5	5 To 15
Hours of operation	24	Maximum 24
Cost of ethanol distillation unit	$68,000	
Cost of energy ($/1000 cubic feet of Natural Gas)	13.70	
Labor cost ($/hour)	12.00	8 To 20
Number full time employees	5	
Shift duration (hours)	8	
Additional set-up and shut down time for distillation unit (days)	20	
% of alcohol in beer	8	8 To 16
Distillation unit cost ($/gallons)	***0.06***	
Labor cost ($/acre)	***30.80***	
Operating cost of distillation ($/acre)	***88.90***	
Depreciation cost of ethanol distillation unit ($/acre)	***8.16***	
Total Ethanol distillation cost ($/acre)	***127.86***	

VITA

Prashant V. Bele

Candidate for the Degree of

Master of Science

Thesis: ECONOMICS OF ON-FARM ETHANOL PRODUCTION

USING SWEET SORGHUM

Major Field: Biosystems and Agricultural Engineering

Biographical:

Personal Data: Born in Pune, India on December 9, 1976 the son of Dr. V. R. Bele and Dr. Mrs. C.V. Bele married to Dr. V.R. Bele

Education: Graduated from University of Pune with Degree in Bachelor of Production Engineering in 1999. Graduated from Oklahoma State University with Master of Science in Industrial Engineering & Management in 2003. A Certified in Production Inventory Management by American Production Inventory Control Society (APICS). Completed the requirements for the Masters of Science degree with a major in Biosystems and Agricultural Engineering at Oklahoma State University in May, 2007.

Experience: Intern-Manufacturing Engineer at Eaton Corporation, Hutchinson KS (May 2005 to August 2005); employed by Department of Biosystems and Agricultural Engineering, Oklahoma State University as Research Assistant, 2002 to present.

Name: Prashant V. Bele Date of Degree: May, 2007

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: ON-FARM ETHANOL PRODUCTION USING SWEET SORGHUM

Pages in Study: 49 Candidate for the Degree of Master of Science

Major Field: Biosystems and Agricultural Engineering

Scope and Method of Study:

Specific objective of the study was to evaluate the feasibility of production of ethanol on-farm using sweet sorghum as primary feed stock. The study would help evaluate the possible scenarios, requirements and difficulties while putting this concept in practice in an economical way. The study included analysis through OSU Enterprise Budget software and Harvester software. The parameters were evaluated for 500, 1000 and 1500 acres harvested with low, medium and high inputs.

Findings and Conclusions:

The study involved many assumptions based on the expert opinion and author's judgments. The on-farm ethanol production is an economically feasible concept through proper land size selection, harvester machine efficiency, sweet sorghum yield, and investment in appropriate equipments. It can be said confidently that to maximize the returns to the investment, a group of farmers should form a cooperative, making mere land and investments available. The investment and returns ratio is not lucrative at lower land size.

ADVISER'S APPROVAL: Dr. Raymond L. Huhnke