AN ECONOMIC EVALUATION OF *ARTEMESIA ANNUA* PRODUCTION

by

ZEKE BRYANT

(Under the Direction of Greg Colson)

ABSTRACT

Artemisinin, a derivative of the plant *Artemesia annua*, is the key compound used in producing medicines for drug-resistant malaria. Mostly grown by small farmers in East Asia and East Africa, there exists a lack of high-yielding genotypes in the artemesia market. Following successful research at the University of Georgia to produce improved varieties of artemesia, an economic evaluation of producing these varieties was performed. An enterprise budget was created for this analysis and fixed and variable costs were accounted for based on reasonable assumptions. Prices and yields were varied at pessimistic, average, and optimistic levels. Costs, prices, and yields were calculated into a sensitivity analysis to estimate net present values for a five acre farm operated for three years. Average price and average yield show a net present value of $129,416 over three years, signaling artemesia to be an economically viable crop in Georgia and likely across the Southern U.S.

INDEX WORDS: *Artemesia annua,* Artemisinin, Enterprise Budget, Malaria

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DEDICATION

I dedicate this paper and my time at the University of Georgia to my parents; who above anyone else have continued to push, encourage, and support me in all of my endeavors. Thank you mom, dad, and the rest of my family who have also been there for me when I have needed them.

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INTRODUCTION

Background

Malaria is a deadly infection of the red blood cells caused by four different parasites of the *Plasmodium* genus and is transmitted to humans via infected members of the *Anopheles* genus of mosquitos. Malaria was responsible for an estimated 627,000 deaths in 2012 (estimates range from 473,000 to 789,000) and most of these deaths occurred in sub-Saharan Africa (90%) and in children under the age of five (77%) (WHO, 2013). There were an estimated 3.4 billion people at risk of malaria in 2012, with 1.2 billion people under high risk while living in sub-Saharan Africa and Southeast Asia. There were 207 million estimated cases of malaria around the world in 2012 (estimates range from 135 to 287 million) with 80% of those occurring in sub-Saharan Africa. Of the four Plasmodium parasites that transmit malaria, *Plasmodium falciparum* is the most deadly and prevalent in Africa. It is nearly resistant to all prior forms of treatment. More commonly found in Southeast Asia, *Plasmodium vivax* is a close second in terms of causing harm and is starting to show resistance to current treatments. *P. malaria* and *P. ovule* are not as troublesome and cause lower percentages of malaria cases and deaths (WHO, 2013).

In response to increasing drug resistance among *P. falciparum* to traditional quinine-based drugs (chloroquine) and rising mortality rates of malaria worldwide, the World Health Organization first suggested in 2001 that artemisinin based combination therapies (ACTs) could help to turn the tide against the drug-resistant malaria infections (WHO, 2001; Ellman, 2010). This action led to the Global Fund for AIDS, Tuberculosis, and Malaria (GFATM) to move their financial support of chloroquine or sulphadoxine-pyrimethamine malaria therapies to ACTs in 2004 (Kinderman et al, 2007). In 2006, the WHO confirmed that ACTs should be the first line of defense against all forms of falciparum malaria (WHO, 2006).

Artemisinin is a chemical compound that is derived from the *Artemesia annua* plant, commonly known as sweet wormwood, and is indigenous to China (Ellman, 2010; Kinderman et al, 2007). Artemesia has been used in teas for over 2000 years to treat fevers and other symptoms associated with malaria in China, but these teas have been found to contain marginal medicinal value (WHO, 2006; Ellman, 2010). In the 1970's, Chinese scientists derived artemisinin from the Artemesia plant due to growing pressures of drug resistant malaria in China and North Korea (WHO, 2006). Despite this, it took 40 years to realize the compounds full potential.

Production, Supply Chain, and Demand

The actions of GFATM and the WHO of the early 2000's had major consequences for the artemisinin market, Chinese and African farmers, and the malarial drug market as a whole. Up until that early 2000's, nearly all artemesia was grown, harvested, and processed for artemisinin in China and Vietnam; the market was in more or less equilibrium (Kinderman et al, 2007). After the WHO call for ACTs in 2001 22 countries moved to the use of ACTs as a first line defense over the course of three years, but after GFATM's 2004 announcement 18 countries nearly simultaneously named ACTs as a first line defense (WHO, 2004). The jump in the WHO demand for ACTs went from 220,000 treatments in 2001, to 10 million in 2004 with forecasts for 60 million treatments in 2005. Since the announcement occurred in late 2004, farmers had already made planting decisions for that year. The growing time of artemesia is roughly 5 to 7 months and then it takes another 3 to 5 months to extract and process artemisinin and its derivatives (WHO, 2004). Thus, a severe shortage of artemisinin occurred and prices skyrocketed from $350/kg to over $1000/kg (Kinderman et al, 2007). In 2005 small farmers in China and Vietnam greatly increased planting of Artemesia with the hope of higher prices and commercial cultivation of the crop began in East African nations (Kinderman, 2007). These increases in artemesia production continued through the 2006 and 2007 growing seasons and when forecasts for 2007 treatment demand stayed flat compared to 2006 demands, the prices eventually bottomed out, going so low as $200/kg in 2008 (Kinderman et al, 2007; Ellman, 2010). Now that the market shock has stabilized, the average price or 'fair price' is between $350 and $400 per kilogram for artemisinin (Lin, 2013; Laux and Subbiah, 2013).

Before 2004, most of the artemesia that was collected came from wild plants that grew along roadsides, in people's backyards, or forest stands along with some cultivated fields showing up in China and Vietnam after the discovery of artemisinin and rising drug resistance at the end of the 20th century. The dry leaf yield and artemisinin yield were both very low, 500kg dry leaves per hectare and 0.03 to 0.3% by weight, respectively. In the 1990's, some European research organizations began to take notice of artemesia and one in particular (Mediplant) created a higher yielding variety which increased both dry leaf output and artemisinin content to 2.5 metric tons of dry leaf per hectare and 1 to 1.55%, respectively. Since the move to make ACTs a major factor in fighting malaria several universities and research firms have attempted to make higher yielding varieties of artemesia through increasing biomass and artemisinin content (Ellman, 2010). Despite these efforts, average artemisinin content remains approximately 1% among major production countries (China - 0.7%, Vietnam - 0.7%, East Africa - 1.0%, Madagascar - 1.1%, and India - 0.8%). However, there have been improvements in increasing artemisinin per hectare, mainly by increasing leaf size (Pilloy et al, 2013).

The majority of artemesia production still occurs in China, as well as the majority of artemisinin manufacturing. Of the 50,000 to 75,000 acres of artemesia planted in 2013, 50% of it was in China, 20% in East Africa, 15% in Vietnam and 10% in Madagascar. Roughly 80% of this production was by small farmers. The average farm size in East Africa and Madagascar was just over an acre and farm sizes in China a little smaller. As far as extraction, there are only ten factories across the globe that can produce 20 metric tons of artemisinin per year. There are other, smaller extractors, mostly in China and Vietnam, but many of these do not meet WHO standards. Eight of these large factories are in China, one in Kenya, and one in Madagascar. Once the artemisinin has been extracted and placed into a crude, cake form, it is shipped to WHO approved pharmaceutical companies in China, India, France, and Switzerland who refine it and process it into the final combination therapy. To stall rapid development of resistance to artemisinin antimalarials, the WHO maintains that the artemisinin based drugs be combined with other drugs to assist in destroying the remaining 5% of parasites that remain after a 3 day course of artemisinin based treatments is given. Given these standards, it is easy to see why only a few places in the world create the ACTs (Ellman, 2014).

In 2012, there were an estimated 331 million treatments of ACTs given (WHO, 2013). The forecast for the demands for ACTs remains around this number. This would require roughly 180 metric tons of artemisinin coming from about 75,000 acres of artemesia (given good agricultural practices and proper extraction efficiencies). The current cost for each ACT treatment is around $2.00. This number provides farmers and extractors a normal return price for their products, but it is too expensive for malaria sufferers and their governments. Given this apparent problem, ACTs have been heavily subsidized since their introduction to the antimalarial market. Large amounts of funding from the Gates foundation and others have gone to GFATM, so that ACTs may be purchased, nearly at cost, and distributed freely to governments and private organizations. GFATM currently purchases 90% of ACTs produced but this demand has hinged on the support given to the organization. Even though funding for GFATM and ACT purchases has increased greatly since 2002, the funding has a history of being delayed. This has created uncertainty in the market and leaves farmers and extractors uncertain when making future production decisions. Although there is some contracting between extractors and farmers, most of this is in African production while the majority of production in China is less regulated leaving the market open to instabilities (boom and bust cycles). There has been research at University of California, Berkley on methods of producing artemisinin in a laboratory, with hopes to stabilize the market and reduce artemisinin production costs. Currently this method is still more expensive than cultivated artemesia and its antimalarial effectiveness has not been established (Ellman, 2014). The production goals of this project are to produce 35 metric tons of artemisinin per year, but final WHO certification and the cost of production still remain barriers (Laux and Subbiah, 2013).

Artemesia Research at the University of Georgia

Over the past few years, the University of Georgia (UGA) Horticulture Department has been doing research on improving the yield efficiencies of artemesia. Under the direction of Dr. Hazel Wetzstein, there have been significant gains in both artemisinin content within the leaves and in leaf size. This was accomplished by first selecting high-yielding genotypes of artemesia that exhibited increased biomass and artemisinin content. These genotypes were then put through cross breeding and high yielding individuals were selected to continue the process. This procedure continued until six genotypes were identified to have favorable, repeatable physiological traits. The best individuals from these genotypes were then selected and cuttings made from them were then planted for vegetative propagation. Field plots were carried out on the six genotypes at the UGA Horticulture Farms using one meter plant and row spacing (10,000 plants per hectare). The plants were then harvested and analyzed for total plant fresh weight, total plant dry weight, stem dry weight, leaf dry weight, artemisinin content, and kilograms per hectare artemisinin (the last three of which are of economic importance). Dry leaf weight ranged from 2.46 to 3.88 metric tons per hectare (Mediplants hybrids achieved 2.5 metric tons per hectare). Artemisinin content ranged from 1.64% to 2.62% (Chinese average of 0.7%). Finally, kilograms of artemisinin per hectare ranged from 43.5 to 83.5 (average in China in 2012 was 13.5). These efficiency improvements equal to a range of 3.2 to 6.2 times the average production of Chinese growers (Pilloy et al, 2013; Wetzstein, 2014).

Problem Statement

Given the significant efficiency improvements of artemesia production at the University of Georgia, the question remains whether commercial production of the crop is a viable investment endeavor for producers. In order to determine the economic viability of producing artemesia, this study develops an enterprise budget analysis. This assessment includes all reasonable costs of producing the crop and expected production outputs and compares this to expected prices a supplier may face on the global market. The objective is to provide such a budget and determine the potential economic feasibility of growing artemesia. The study bases the production of the crop in Georgia but it is easily applicable to several states across the Southeastern U.S. where climate and agricultural production practices are analogous.

CHAPTER TWO

LITERATURE REVIEW

Background

The literature review for this analysis will cover current production practices and production related information of *A. annua* in industry publications. There are two main sources, both of which were created under the direction of WHO and other international programs. The first published source of this material is from East African Botanicals Ltd. (EABL) in April, 2005. Titled, “Growers Production Manual for *Artemesia annua*”, the manual lays out proper cultivation practices for large and small farmers in East African countries (EABL, 2005). The second main source of information for artemesia cultivation was published in 2006 after WHO organized meetings that included producers in China and East African countries and other experts. The publication was titled, “WHO Monograph on Good Agricultural and Collection Practices (GACP) for *Artemesia annua* L.” The publication included proper cultivation and harvesting techniques, pharmacological properties, quality control requirements, and quality specification for artemisinin and its chemical products (WHO, 2006). It is mainly from these documents that information for planning, growing, and harvesting a crop of artemesia will be employed. Given some of the differences between the technological, labor, and capital aspects of the U.S. agricultural industry and others’ such as China and East African countries, some adaptations to agricultural practices are required. Along with these adaptations, several reasonable assumptions will have to be made since there is no data on commercial artemesia production in the U.S. Many of these assumptions are based on current tobacco cultivation practices in the Southern U.S. Some of this information comes from personal experience in tobacco cultivation and interviews, and others from tobacco budget publications.

Planning and Pre-Planting

Site selection and proper planning is key to any new agricultural endeavor. Artemesia is a very adaptable, hardy plant that has been naturalized in many areas of the world (WHO, 2006). It prefers sunny, warm conditions but has also been documented to grow well in the shade (EABL, 2005; WHO, 2006). It has been shows to grow well at several different altitudes across different countries such as 50 to 500 meters in Vietnam and 1000 to 1500 meters in Kenya (WHO, 2006). A soil test should be conducted before any planting as artemesia prefers soils between a pH of 5.5 and 6.5 (EABL, 2005). Lime should be applied accordingly for soils below a pH of 5.5 and typically prior to two months before planting (WHO, 2006). Artemesia generally requires a six month time frame for growth which would be suitable to Georgia’s long summers. Artemesia prefers an area that receives between 1150 mm (45 in.) and 1350 mm (53 in.) of annual rainfall, which matches Georgia rainfall (GDEcD, 2014; WHO, 2006). Since our calculations will include a drip irrigation system for artemesia cultivation, which is recommended, this point is less significant (Ellman, 2010). Altitude, temperature, rainfall, soil characteristics, and harvesting methods are all factors that have yet to be definitively shown how they affect final artemisinin content, which is why test plots are suggested first (WHO, 2006). It is reasonable to assume that most of these factors are consistent across Georgia except for far North Georgia and the coastal areas. Since the test plots carried out at the UGA horticulture farm were successful in terms of yield, most of Georgia’s climate, as well as the climate of surrounding states, would result in very promising efficient artemisinin production.

Soil Preparation

The first step for soil preparation is a reliable soil test to determine the correct pH and if any macronutrients are lacking. Apply lime and other nutrients as needed. As with other crops, proper plowing, weed control, and levelling the field should take place (WHO, 2006). Artemesia plants generally do better in raised beds, especially during rainy seasons since the root system can be fragile when young (EABL, 2005).

Nursery and Planting

In this analysis the plants are grown via vegetative propagation from selected parents that are high yielding cultivars. It is assumed starting a nursery along with this experimental crop is not feasible, which is why it is suggested that a farmer contract with a nursery to grow the plants. Preferably the nursery would be housed within a greenhouse. This protects the young plants from weather elements in a more controlled environment and also protects from disease and pests (EABL, 2005). Plants should remain in the nursery for at least seven weeks and great care should be taken during this phase. If the young plants are stressed or roots become damaged, the plant may flower early resulting in decreased yields (Ellman, 2010).

Planting for the field test plots was done at a planting density of one meter by one meter (10,000 plants per hectare or 4050 plants per acre). This is the suggested planting density for F1 hybrids, which these plants are. The planting density was 36 inches by 36 inches to accommodate for Imperial System measurements and technology. Four rows were planted, with an eight foot sled row separating each four-row group to accommodate for crop maintenance.

Fertilizing

There are some differing theories on what time is best to apply fertilizers and it mostly depends on how the crop is growing in that particular area. The consensus is that the plants require nitrogen and phosphorous at initial branching stages, phosphorous before blooming, and the requirements for potassium increases linearly from planting through branching. Initial branching typically occurs around two months after transplanting and flowering often occurs six months after transplanting (WHO, 2006). It is also suggested that at least one micronutrient fertilization should be applied to increase artemisinin development. This foliar fertilization typically occurs either at four weeks or eight weeks post-transplant (EABL, 2005).

Weeding, Pest, and Disease Management

A general herbicide should be used before planting to control for weeds. Once establishment of the plants have occurred, they grow vigorously enough to crowd out most weeds. An herbicide containing glyphosate is often recommended and used (EABL, 2005). Since artemesia has not been cultivated on a wide scale for very long it lacks major pest and disease issues, enjoying a type of 'honeymoon period.' Most of the pest problems associated with artemesia are caused by aphids and beetles and there is some evidence of bacterial damage to stems. General insecticides should be applied on a needed basis (Ellman, 2010).

Irrigation

A rain fed crop of artemesia requires roughly 23 to 26 inches of rain during its growth (EABL, 2005). Ensuring the plants receive as much water as needed maximizes leaf size, artemisinin content, and prevents the plant from flowering early (Ellman, 2010). During test plots, the plants were under drip irrigation and this will also be adopted for this analysis.

Harvesting and Storage

Plants are typically harvested before flowering, as during and after flowering artemisinin content severely declines. Up until flowering, during the late stages of growth, artemisinin content rises; this leaves a small window for harvesting. Harvesting is typically initiated once half to three-quarters of the plants show that flower buds have started to grow. This is when it is believed that artemisinin content is highest (EABL, 2005). Since the plants in this analysis are all clones, they should mature at the same time. In Africa and in Asia, harvesting is typically all done by hand using pangas or machetes to cut the plant at the base. The plants are then laid out flat or stoked in a field for five to ten days to allow them to air dry in the sun. Sun drying has been shown to be the best method as artemisinin is an unstable compound and breaks down at high temperatures, thus removing the possibility of using a tobacco curing method. Plants should not be stacked in a way that restricts air flow or compresses the plants, as this causes rot and should also be kept out of the rain. Once the plants have reached roughly 12% moisture content, the leaves are ready to be removed from the plant. Dry leaf removal can be done either by hand or by running over dried plants with a tractor, both over tarpaulins to prevent losses. Either way, removal is a labor intensive process. We will be assuming removal by hand for this analysis, as it typically does not require further sieving. The plants can be shaken or beaten onto the tarpaulin, coupled with hand removal of remaining parts, to gather most of the dried leafs. Once this is completed the dried leaves should be stored in breathable bags and moved to covered storage (EABL, 2005; WHO, 2006).

Extraction

Typically once the growers have the bags of dried leaves ready and in storage, they are shipped off to a primary artemisinin extraction plant. Transporting the dried leaves is recommended as soon as possible as artemisinin content slowly declines and is gone in terms of production after six months (Ellman, 2014) Once at the extraction facilities, the artemisinin is derived and then sent to pharmaceutical factories where the ACTs are produced (Ellman, 2014). Since there are no artemisinin extraction plants in North America, a small extraction unit would have to be purchased. In 2007, a research team at the University of Bath in the United Kingdom investigated different artemisinin extraction processes in order to determine better methods and the feasibility of a mobile, “back of a truck” extraction unit. It was found that an extraction process using ionic liquids, capable of handling up to 5,500 tons of dry leaf per year could be realistically purchased by a grower with access to enough capital. The extraction process requires little time, with only one step needed to separate the artemisinin from the leaves (Lapkin et al, 2007). Once extraction is complete, the artemisinin should be stored in cake form in a cool dry place (WHO, 2006).

CHAPTER 3

METHODS AND DATA

Background and Assumptions

For the purposes of this analysis, a five acre farm operating over the course of three years is assumed. Further, it is assumed a potential grower would not risk additional land or time on an experimental crop. Also, a 5% interest rate is assumed for all costs and discounting. Many of the ideas such as required farm equipment, planting procedures, and variable costs come from tobacco enterprise budgets prepared by extension economists in Georgia, North Carolina, and Virginia. All of the prices are for new equipment and inputs and were gathered through phone interviews, the internet, or from enterprise budgets; priority was placed on products in or as close as possible to Georgia. One of the major drawbacks of this analysis is that artemesia is not currently commercially grown in North America. This left room open for creativity in planning out pre-harvest, harvest, and extraction methods and these methods may or not be feasible in a real-world environment.

Land Preparation

An average price for rented farmland in Georgia, no specific crop and non-irrigated, was used for this study. The prices come from a published study of cash rents paid for different cropland prices in Georgia by an agricultural economist at UGA (Escalante, 2010). A farm size of five acres, 36” by 36” plant and row spacing, and eight foot sled rows every four rows is to be used. With rows 600’ long, 73 rows consisting of 200 plants each yield a total number of 14,600 plants per acre. For field preparation, we assumed the field should be harrowed three times and field cultivated once. This depends on the condition of the land but is a reasonable expectation given current farm practices. Disk bedding, along with bed shaping, should be done in order to prepare the rows for transplanting.

Estimated Fixed Costs

There were several investments to be considered for land preparation, planting, maintenance, harvesting, and extraction. The prices for most of the agricultural equipment come from John Deere and other equipment dealers. A mid-size tractor was chosen in order to ensure that all farm operations could be performed at an efficient cost. The sickle bar mower is to be used for harvesting. Since it is six feet long, two rows can be mowed at once. The Mechanical Transplanter is a model 1000B-3 and is one often used in small tobacco planting operations. It sits eight people in order to plant four rows at a time. A decent sized truck is needed in order to haul equipment, workers, and plants around the farm. A flatbed trailer was used in this analysis in order to transport equipment and bags of dried artemesia leaves once harvested. A storage building is needed in order to store the dried leaves and to house the extraction unit. At 1,632 square feet, a 34’ long by 48’ wide building should be sufficient. Burlap sheets are to be used in order to store the dried leaves, in much the same way tobacco leaves used to be stored. At 200 pounds per tied-up sheet, 85 sheets are the minimum required for the size of this operation. The tarpaulins are to be used to dry and separate out the leaves. The price of the small extraction unit was taken from the previously mentioned U.K. study and it was an approximation based on that study (Lapkin et al, 2007). A Euro to U.S. Dollar conversion rate of 1.36 was used for this calculation. A 20% salvage value was used across the board on all equipment for depreciation purposes. Years of life were reasonably assumed and also referenced from similar works by Fonsah et al, (2005). A straight line depreciation method was used as well. Interest was calculated as the average interest rate that would be paid over the life of the equipment at the fixed interest rate of 5%. For example, the interest paid on the tractor was calculated as the interest paid on purchase price in year one, interest paid on purchase price minus depreciation in year two, remaining value minus depreciation in year three, up until the salvage value had been reached. These values were then averaged over time. Taxes and insurance were assumed to be 0.15% of the total purchase price. This number was derived from similar studies (Fonsah et al, 2005; Plattner, 2008). Finally an estimate of fixed costs per acre was derived, which equaled to $4,903 per acre per year.

Table 1. Estimated annual fixed costs per acre for machinery and investments on a 5 acre farm of *Artemesia annua* . Assumes a 5% interest rate.

Item[1]	Purchase Price ($)	Salvage Value ($)	Life (years)	Depreciation ($)	Interest ($)	Taxes and Insurance ($)	Fixed Cost ($/Acre)
Tractor (57-61 hp)	24,310.00	4,862.00	20.00	972.40	729.30	364.65	413.27
Sickle Bar Mower (6')	4,800.00	960.00	7.00	548.57	144.00	72.00	152.91
Disk Harrow (8')	4,338.00	867.60	10.00	347.04	130.14	65.07	108.45
Mechanical Transplanter (4-row)	10,100.00	2,020.00	10.00	808.00	303.00	151.50	252.50
Field Cultivator (6')	832.00	166.40	10.00	66.56	24.96	12.48	20.80
Boom Sprayer (12', 55 gal.)	1,370.00	274.00	5.00	219.20	41.10	20.55	56.17
Truck	30,000.00	6,000.00	20.00	1,200.00	900.00	450.00	510.00
Trailer (7'x16')	2,500.00	500.00	20.00	100.00	75.00	37.50	42.50
Bedder (4-row)	12,000.00	2,400.00	10.00	960.00	360.00	180.00	300.00
Bed Shaper (4-row)	11,500.00	2,300.00	10.00	920.00	345.00	172.50	287.50
Storage Building (34'Wx17'Hx48'L)	10,349.00	2,069.80	25.00	331.17	310.47	155.24	159.37
Burlap Sheets for Storage (x85)	850.00	170.00	5.00	136.00	25.50	12.75	34.85
Tarpaulin (x2)	354.00	70.80	5.00	56.64	10.62	5.31	14.51
Small Extraction Unit	150,000.00	30,000.00	20.00	6,000.00	4,500.00	2,250.00	2,550.00
Total Investment	**263,303.00**	**52,660.60**		**12,665.58**	**7,899.09**	**3,949.55**	
Total Fixed Cost							**24,514.21**
Total Fixed Costs/Acre							**4,902.84**

[1] All prices are for new equipment. Used equipment could be purchased or equipment could be leased/rented for lower costs

Drip Irrigation Costs

The drip irrigation for this analysis was assumed to be small and as efficient as it could be. A five horsepower motor and 300’ deep well capable of pumping 50 gallons per minute were assumed. For planning purposes and some cost data, a Toro Inc. representative was contacted. What information was left to be gathered was done so through online prices and from the study on organic blueberry production previously mentioned (Plattner, 2008). Life of equipment, depreciation, interest, and taxes and insurance were all calculated in the same manner as the fixed costs for machinery. This does exclude salvage value, as there is no salvage value assumed for this system. Annual pumping hours was based on the number of acres being irrigated and the water requirements of artemesia. Standby charge and the rate charge for kilowatt hours was determined through Georgia Power’s bill calculator for the summer rate. The kilowatt hours used pumping were obtained from documents provided online by Great River Energy and were based on the motor size and depth of well (Great River Energy, 2011). Total fixed costs for the drip irrigation system came out to $248 per acre, while operating costs were $35 per acre leaving a total cost for drip irrigation at $283 per acre per year.

Table 2. Estimated annual costs per acre for a drip irrigation system for producing *Artemesia annua* on 5 acres. Assumed a 5% interest rate.

Investments and Fixed Costs

Item	**Purchase Price ($)**	**Life (years)**	**Depreciation ($)**	**Interest ($)**	**Taxes and Insurance ($)**	**Annual Fixed Cost ($/Acre)**
Pipe and Fittings	660.00	20.00	33.00	16.50	4.95	10.89
Drip Tape	480.00	7.00	68.57	12.00	3.60	16.83
Well (4", 50 gals/min)[2]	4,000.00	25.00	160.00	100.00	30.00	58.00
Pump and Motor (5hp)	4,000.00	15.00	266.67	100.00	30.00	79.33
Filters	1,000.00	10.00	100.00	25.00	7.50	26.50
Water Meter	1,500.00	10.00	150.00	37.50	11.25	39.75
Installation	1,000.00	20.00	50.00	25.00	7.50	16.50
Total Investment	**12,640.00**		**828.24**	**316.00**	**94.80**	
Total Annual Fixed Costs						**1,239.04**
Annual Fixed Costs/Acre						**247.81**

Operating Costs		**Energy Costs ($)**	**Annual Costs ($)**	**Annual Operating Costs ($)**
Repairs			50	
Annual Pumping Hours	240			
Electricity				
Demand (standby charge)	72			
Rate ($/kWh)	0.11			
kWh Used Pumping	1,080			
Energy Costs		127		
Annual Energy Costs/Acre				**25**
Annual Operating Cost/Acre				**35**
Total Annual Cost/Acre				**283**

[1] All equipment purchased new

[2] Well depth is 300'

Operating Costs

Once again, a 5% interest rate was used on operating costs. Labor was contracted at a flat rate of $12 per hour due to general consensus among tobacco enterprise budgets. Plant prices were difficult to come by. The only major row crops producing in North America by vegetative propagation are sugar cane, potatoes, and sweet potatoes. Sugar cane propagation is typically done in house and cuttings are rarely sold off the farm (LSU, 2014). Potatoes and sweet potatoes are completely different kinds of crops compared to artemesia, so no reasonable assumption could be made there. Instead, prices for tobacco plants were used as a substitute. Typically grown from seed then transplanted into fields, tobacco plants are similar to artemesia in that they are sensitive at transplant and the leaves are harvested for further use. However, it could be suggested that artemesia plants created via vegetative propagation would be more expensive, but since it is not known how much more expensive this point should be noted but unrecognized in this analysis. The prices for fertilizers, herbicides, and insecticides were taken from local agricultural supply stores and their applications follow from what was suggested in the literature review. The labor costs for planting were for five workers; four on the planter and one driver. The rest of the labor costs for field machinery work was done for one laborer who is operating the tractor. The number of hours taken up by the different activities involving tractor labor were done by assuming a constant tractor speed of two miles per hour and calculating the length of distance traveled by the tractor for each separate piece of machinery. For example, planting is done four rows at a time over 73 rows. This gives us a required 19 trips of 600’ by the tractor. At 2 miles per hour the tractor will cover that distance in approximately 1.08 hours. Divide this number by 5 acres and the hours per acre is calculated. Fuel was calculated as diesel costing an average of $3.60 per gallon multiplied by the product of the tractors maximum p.t.o. horsepower (61 hp.) and a fuel consumption multiplier, 0.048 in this case. This was multiplied by the total number of tractor hours per acre, which gives us the cost per hour per acre. Lubrication was calculated as 15% of total fuel costs (Clemson University, 2014). The labor cost for harvesting is the cost for one laborer to run the sickle bar mower, which can harvest two rows at a time at a length of six feet (36” row spacing), while it is attached to the tractor. With 73 rows the mower will need to make 37 trips of 600’ at two miles per hour, which comes out to a total hours per acre time of 0.42. The labor costs for stooking the plants in the field are calculated as the time it takes five workers to stook each plant multiplied by the labor cost of $12.00 per hour. If it is assumed that stooking takes 30 seconds per plant (14,600 plants) then a total time per acre of 24.5 hours is found. Divide this number by the number of workers (5) and multiply by the total labor costs (5*$12=$60) to get the estimated labor costs per acre for stooking the plants. The labor costs associated with manual leaf extraction are very similar. A time of one minute per plant for leaf removal by five workers is assumed. Following the previous calculation, this gives us a total time of 48.5 hours for leaf removal and a per worker time of 9.7 hours. The operating costs for extraction by an ionic liquid method were taken from the previously mentioned study on small extraction units and a Euro to U.S. Dollar conversion rate of 1.36 was used again for this cost (Lapkin et al. 2007). The costs for land were the average cash rents paid for non-irrigated, non-crop specific land in Georgia, which is typically paid monthly but the annual costs were calculated for this study (Escalante, 2010). Interest was calculated as an average as it was done in the drip irrigation calculations and included the sum of all per acre operating and land costs except for management and overhead. Management and overhead were calculated as 15% of the sum of all operating and land costs.

Table 3. Estimated operating costs per acre for a 5 acre farm of *Artemesia annua*. Assumes a 5% interest rate.

Pre-Harvest

Item	No. of Applications/ Year	Unit	Quantity/ Acre	Price/ Application ($)	Costs/Acre ($)
Plants	1	Thousands	2920	30	87.6
Herbicide (glyphosphate)	1	acre	1	60	60
Insecticide (Orthene 97)	2	lbs.	1	15	30
Fertilizer (20-20-20)	3	lbs.	5	8	16
Fertilizer (Micronutrients)	1	lbs.	45	187	187
Planting-Labor	1	hours	0.21	60	12.6
Harrowing-Labor	3	hours	0.5	12	18
Field Cultivating-Labor	2	hours	0.69	12	16.6
Bedding-Labor	1	hours	0.21	12	2.5
Bed Shaping-Labor	1	hours	0.21	12	2.5
Spraying-Labor	7	hours	0.21	12	17.6
Fuel and Lubrication[1]	-	hours	2	3.6	24.8

Harvest

Item	No. of Applications/ Year	Unit	Quantity/ Acre	Price/ Application ($)	Costs/Acre ($)
Harvesting-Labor	1	hours	0.42	12	5.0
Stooking Plants-Labor	1	hours	4.9	60	294
Manual Leaf Removal/Storing-Labor	1	hours	9.7	60	582
Fuel and Lubrication	-	hours	1	3.6	12.4
Post-Harvest					
Extraction Costs	1	lb	44	13.5	594
Other Costs (fixed or variable)					
Land-Rented, Dry (no specific crop)	1	acre	1	1	518
Interest on Operating Costs					62
Overhead and Management[2]					372
Total Operating Costs/Acre					**3002**

[1] Lubrication costs were allocated as 15% of fuel expenses

[2] Overhead and Management were assumed to be 15% of total operating expenses

Prices and Yields

Prices were taken from presentations made at WHO Artemisinin conferences over the past several years. Three prices were chosen to be used for this analysis; a low price, average price, and high price. The low price is the lowest recorded average price for artemisinin and occurred in 2007. The average price comes from the average annual prices for artemisinin from 2002 to 2012. The high price is the highest recorded average annual price and occurred in 2005 (Pilloy, 2009; Pilloy et al, 2013). There were also three different yield amounts used in calculations and these were taken from the 2013 artemesia field study done at the UGA Horticulture Farm as well as yields from the WHO Artemisinin conferences (Pilloy et al, 2013). The low yield level is based on the average kilograms of artemisinin per hectare produced in China for 2012 (Pilloy et al, 2013). This level is used in the calculations in order to create a comparison between production in the U.S. and the world market leader. The average yield is the average yield of all six improved genotypes. The high yield is the highest recorded artemisinin level of the six different genotypes (Wetzstein, 2014). Also for this study, a breakeven price and yield were calculated based on the costs, prices, and yields. The breakeven price is calculated as,

$$breakeven\ price = estimated\ total\ costs \div expected\ yield$$

and the breakeven yield is calculated as

$$breakeven\ yield = estimated\ total\ costs \div expected\ price.$$

The breakeven price represents the threshold at which the price per unit covers total costs at the expected yields. The breakeven yield is the minimum yield necessary for total costs to be covered by the expected prices (Greaser and Harper, 1994).

CHAPTER 4

RESULTS AND DISCUSSION

Total Costs

The total costs for the farm and per acre were calculated in table 4 and they included total fixed costs, total drip irrigation costs, and total operating costs plus land rental. The estimated total cost per acre of $8,188 for this small operation are high, but that is to be expected since this is an experimental crop. Purchasing used equipment, leasing, or using existing equipment could greatly reduce some of this cost. Also, finding a more technology based leaf extraction method could reduce high labor costs associated with that part of production. An important cost that was left out of this analysis was shipping expenses, which could significantly raise the prices. Some of the reasons this cost was left out were because there are many international locations the final product is shipped to and it is unclear which party pays for the shipping of the product since artemisinin is heavily subsidized toward the final end product.

Table 4. Total estimated costs of producing 5 acres of *Artemesia annua*

		Costs ($)		Costs/Acre ($)
Total Fixed Costs		24515		4903
Total Drip Irrigation Costs		1415		283
Total Operating Costs		15010		3002
Total Farm Costs/Acre/Year		**40940**		**8188**

Breakeven Prices and Yields

In Tables 5, 6, 7, and 8 the breakeven prices and yields were calculated at the different price and yield levels previously mentioned. The yields for artemisinin are listed per acre and total at pessimistic, average, and optimistic levels and represent the yields from the experimental field plots of artemesia and subsequent extraction and the average yield in China for 2012 (Pilloy et al, 2013). The expected prices are averages from the previously listed sources and have been adjusted to dollars per pound instead of kilogram. A breakeven price and yield was calculated for each of our possible yields and prices. The highest breakeven price of $680.17 represents the minimum price necessary to cover the costs associated with a yield of 12.04 pounds of artemisinin per acre. This breakeven price is significant because it shows that at the same yields or artemisinin as China, production in the U.S. would require a much higher average world prices than are currently present. The highest breakeven yield of 78.08 pounds of artemisinin per acre indicates the minimum amount necessary to cover the total costs while receiving a price of $104.87 per pound. This number is higher than even our optimistic level of production but this is due to the very low price used in the calculation.

Table 5. Breakeven Price of Artemisinin Extraction (Pessimistic Production Level).

Item	**Pessimistic**
Artemisinin/Acre (lbs.)	12.04
Total Artemisinin (lbs.)	60.20
Expected Price of Artemisinin ($/lb.)	104.87
Breakeven Price ($/lb.)	**680.07**

Table 6. Breakeven Price of Artemisinin Extraction (Average Production Level).

Item	**Average**
Artemisinin/Acre (lbs.)	57.86
Total Artemisinin (lbs.)	289.30
Expected Price of Artemisinin ($/lb.)	297.96
Breakeven Price ($/lb.)	**141.51**

Table 7. Breakeven Price of Artemisinin Extraction (Optimistic Production Level).	
Item	**Optimistic**
Artemisinin/Acre (lbs.)	74.50
Total Artemisinin (lbs.)	372.50
Expected Price of Artemisinin ($/lb.)	678.57
Breakeven Price ($/lb.)	**109.91**

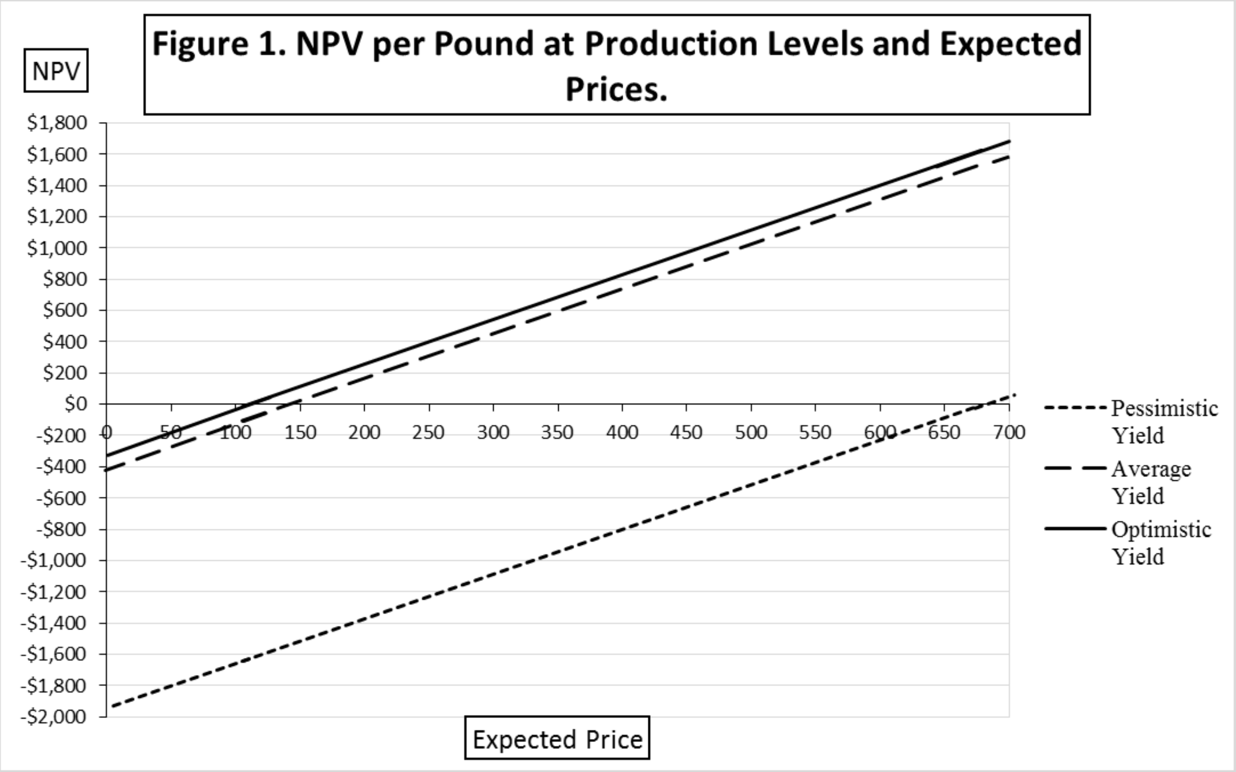
Table 8. Breakeven Yields across all expected prices (lbs.).			
Item	**Pessimistic**	**Average**	**Optimistic**
Total Farm Costs/Acre/Year ($)	8,188.00	8,188.00	8,188.00
Expected Price of Artemisinin ($/lb.)	104.87	297.96	678.57
Breakeven Yield (lbs.)	**78.08**	**27.48**	**12.07**

Net Present Value Sensitivity Analysis

The last part of this study uses a sensitivity analysis across the different expected yields and prices to calculate a three year net present value (NPV) of returns over costs. Each calculation of an NPV assumes that level of production and prices for all three years and a 5% interest rate. For example, the loss of $1644.72 per pound represents receiving the lowest price and achieving the lowest yield for three years in a row. These numbers were calculated by subtracting the expected price by the breakeven price to get net revenue. Payouts were calculated as year zero, year one, and year two for the purposes of the NPV analysis. From the table we can see that no matter what level of production, the farm will operate at a loss given the lowest price. This should not be of much concern since that price occurred in 2007 after large market shifts in late 2004 caused a large surplus of artemesia production in 2005 and 2006. In that same thought, the farm will also operate at a loss no matter the price level given the lowest output level. This is of negligible concern as well, since we are expected much higher yield efficiencies of artemisinin. The market has since mostly stabilized and the prices that most involved parties are aiming for are nearer to the average price that was calculated (Pilloy et al, 2013). The returns across the average price and yields is very promising considering they are well above breaking even. Potential producers should take note of these numbers as they are more realistic to real world possibilities as far as prices and yields are concerned. The net present values at the high price mark and above the lowest production level are very promising but these are just as likely to not occur as the numbers under the low price calculations. The high prices also exist due to market unrest following the GFATM announcements in late 2004 but should supply shocks to artemesia crops occur in Asia or East Africa, these numbers may become more realistic. In Figure 1, we see the range of different NPV amounts across the three production levels given different price points. Also note in Figure 1 that the x-intercept for each line represents its respective breakeven price.

Table 9. Three Year NPV per Pound at Production Levels and Prices. Interest Rate is 5%.

Production level	NPV at Low Price ($/lb.)	NPV at Avg. Price ($/lb.)	NPV at High Price ($/lb)
Pessimistic	-1644.72	-1092.60	-4.28
Average	-104.78	447.34	1535.66
Optimistic	-14.40	537.72	1626.04



Net present values were also calculated on a per acre and total farm revenue basis in figures seven and eight, respectively. While the per acre NPV amounts seem intuitive as they may represent possible losses/increases in revenue with an increase in acreage, it is important to keep in mind that the costs will also rise. This is especially true of fixed and drip irrigation costs which are more dependent on the farm size than operating costs, which would likely increase more linearly. The total farm revenue NPV amounts are interesting in that there is such a large range when the numbers are taken to full scale. While the numbers at the high price seem like hyperbole, the NPV of just over $200,000 at the average price and optimistic yield is very encouraging for a potential farmer. However, there also exist the possibilities for large losses at the low price and low yield levels.

Table 10. Three Year NPV per Acre at Production Levels and Prices. Interest Rate is 5%

Production Level	NPV at Low Price ($/acre)	NPV at Avg. Price ($/acre)	NPV at High Price ($/acre)
Pessimistic	-19802.46	-13154.89	-51.52
Average	-6062.58	25883.28	88853.49
Optimistic	-1072.81	40060.40	121140.25

Table 11. Three Year Farm NPV at Production Levels and Prices. Interest Rate is 5%

Production Level	NPV at Low Price ($)	NPV at Avg. Price ($)	NPV at High Price ($)
Pessimistic	-99012.31	-65774.47	-257.59
Average	-30312.92	129416.42	444267.46
Optimistic	-5364.04	200301.99	605701.26

CHAPTER 5

CLOSE

Conclusions

After research at the University of Georgia to develop high-quality genotypes of *A. annua* was successful and completed, this study was prepared in order to measure the economic capability of producing an artemesia crop. Upon showing that there was a need for artemesia to combat malaria along with a deficiency of high-quality plants throughout the current artemesia producing regions of the world, a market niche was shown to exist for this crop. Reasonable numbers were found for fixed and variable costs including machinery, drip irrigation, labor, and plants. Prices and yields were each accounted for across three different levels and these were then analyzed and compared to the total costs associated with the venture. Finally, net present values were found across the price and yield levels and these numbers were analyzed accordingly.

Despite the large amount of assumptions that were made in the course of this enterprise budget analysis, it seems very plausible that an interested party with access to capital and credit and proper know-how could achieve a high level of revenue for a small farm size. While some of the costs calculated in the analysis could prove to be much higher in reality, many of them could also be greatly reduced through purchasing used or leasing equipment, reducing labor costs, or further mechanizing extraction, just to name a few. From our sensitivity analysis, it would seem that out of any given year, yield, and price there is a real possibility to make positive revenue as long as average or better outcomes are met. This likely chance of success coupled with the total farm NPV at average price and average yield of $129,416 for just five acres of production over three years is a good indicator that artemesia does have the potential to be a viable farm business venture in the state of Georgia and very likely across several states in the Southern U.S.

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