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BIOENERGY CROPPING SYSTEMS ON MARGINAL LAND

By

Stephanie Lyn Smith

A THESIS

Submitted to
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ABSTRACT

BIOENERGY CROPPING SYSTEMS ON MARGINAL LAND

By

Stephanie Lyn Smith

Field trials were conducted in 2007 and 2008 to evaluate the efficacy of identified potential bioenergy crops production on marginal land sites. Treatments of crop including corn (*Zea mays* ssp. *mays*), soybean (*Glycine max* (L.) Merr.), canola (*Brassica napus* L. var. *napus*), sunflower (*Helianthus annuus*), and switchgrass (*Panicum virgatum* L.) were evaluated to determine the highest yielding crop which would produce the most fuel specific to each selected location. Sites selected for the study included a remediated brownfield site (ROSE), two northern marginal sites (LC and UP), and a traditionally cropped site in Ingham County (MSU). Yield of soybean, sunflower, canola, and switchgrass differed between locations; however the traditionally cropped site did not consistently provide higher yields. Measured soil characteristics of fertility did not predict yield returns. Ethanol produced from corn grain was significant ($p<0.05$) among locations, and as latitude increased, ethanol yield decreased. Total oil of soybean responded negatively to increases in latitude however, total oil in canola benefited from increased latitudes. Fatty acid analysis provided results indicating northern locations yielded higher levels of oleic acid in soybean and canola. Switchgrass stands, equal in age, regardless of location, were not significantly different. Considering all factors, additional acreage including brownfields and marginal land sites should be explored to increase crop acreage and biomass available for conversion to bio-based fuel sources.

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INTRODUCTION

In 2009, the operational capacity of Michigan ethanol plants reached 780 million liters requiring 25% of the state's corn acreage (United States Department of Agriculture, National Agriculture Statistics Service, 2008). Additional acreage will require exploration into land not currently under production agriculture. Therefore there is an interest in producing bioenergy crops on marginally productive lands which can include USDA soil classifications of III, IV, as well as VI and VII. Growing biofuel crops on marginal land can offset some of the strain imposed on the food supply by biofuels. Petroleum based fuel supplies are not going to be sufficient to meet our energy needs because global fossil fuels are finite in supply and are becoming more expensive to extract as supplies are diminished. Hubbert (1956) projected the world's oil reserves will be depleted in 2045. Meanwhile, the U.S. is the top ranked nation for petroleum consumption using more than 20 million barrels of petroleum a day (Organization of Petroleum Exporting Countries, 2007). In 2008, world population reached 6.7 billion and in 2050 it is projected 9.4 billion people will inhabit the earth (United States Census Bureau, 2008). This will place unprecedented demands on food and energy resources. Bioenergy crops production on marginal land is increasingly seen as an essential component of future energy plans.

Studies indicated that switchgrass is competitive under marginal conditions (Mooney et al., 2005) and that yields of corn grain and stover removal can be similar to switchgrass yield under marginal environments (Varvel et al., 2008), yet no multi-crop comparisons with starch, cellulose, and oilseeds have been reported. Additionally, little information is available on the growth and quality of bioenergy crop production on remediated brownfield sites. It is currently unknown if marginal land can produce adequate yield to offset capital investment or if crops grown on various types of marginal land will yield fuel of adequate quality.

RATIONALE

In 2008, world population reached 6.7 billion and in 2050, it is projected 9.4 billion people will inhabit the Earth (United States Census Bureau, 2008). Of the total number of inhabitants, the life expectancy of these individuals is also going to increase. In 1996, life expectancy on a worldly basis was 63.1 years while following 2007, expectancy was 65.8 years (United States Census Bureau International, 2008). An increase of population and projected lifespan will result in an increased demand for resources essential for life. Clean water, feed, food, fiber, and fuel will be demands of the growing population which will need to be met. To meet these critical human needs, marginal land will need to be explored for energy production to not disrupt the U.S. food supply chain.

According to several estimates, the world's oil reserves will be depleted in approximately 40 years leaving the world in a fuel shortage resulting in increased oil prices (Dhugga, 2007; Hubbert, 1956). The U.S. does not have adequate petroleum reserves to meet the needs of the growing population as many feel as though U.S. oil had peak production in the 1970's and now does not have a means to meet the growing population's fossil fuel needs of the country (Hirsch et al., 2005). Political instability of oil producing regions coupled with the growing population demand for fuel and increased prices of petroleum prices have spurred interest in alternative fuel sources such as renewable fuels or biofuels, which have gained market strength over the last few years (Dhugga, 2007).

Alternative energy has had a long proven history in the U.S. and the world, one which has been forgotten due to relatively low petroleum prices. Biofuels evolved with the internal compression engine and first reached the public in 1898 when Rudolph Diesel demonstrated the compression ignition engine at the World's Exhibition in Paris. The engine operated using peanut oil which is considered the original biodiesel. Henry Ford's first vehicles, the 1896 Quadracycle and later in 1908 the Model T, were engineered to operate on pure ethanol which was derived from corn grain alcohol (Solomon et al., 2007). During times of petroleum shortages such as World War I and II and the energy crisis of the 1970's, as well as increased petroleum prices and environmental degradation, the United States has reverted to the renewable liquid fuels ethanol and biodiesel (Nass et al., 2007). Today with decreased oil reserves, increasing population base, rising costs of petroleum, political fallout, and increased carbon emissions in the atmosphere, biofuels and renewable energy research appears quite attractive to consumers and is required to meet our societal needs.

Energy security critically impacts foreign policies. A domestic energy source would create an economic stimulus in communities as well as ensure a dependable fuel source (Sutterfield, 2007). The U.S. is vulnerable to oil supply disruptions because the global supply of oil is concentrated geographically as

66% of proven oil reserves are located in the Middle East and only 5 percent are located in North America (NEPDG, 2001). This geographic concentration of oil also funnels governmental power to control energy in the hands of a few producers. Many of these leading countries in world oil production are either ruled by unstable governments or maintain adversarial relationships with the United States (Luft, 2005). U.S. dependency on these countries for oil endangers our national security (Sutterfield, 2007).

Climate change in addition to energy security requires large-scale transition to biofuels (Farrell et al., 2006). Renewable fuels have potential to reduce green house gas emissions (GHG) and global warming potential (GWP) (Griffin and Lave, 2006; Sheehan et al., 1998). Furthermore, Fronning et al. (2008) found fertilization regimes incorporating compost and manure amendments in bioenergy crops can further improve their carbon footprint. Hill et al. (2006) found corn grain ethanol yielded 25% and biodiesel yielded 93% more energy than what was invested in its production. Additionally they found GHG are reduced 12% by the production and combustion of ethanol and 41% by biodiesel. Schmer et al. (2008) showed a life-cycle analysis estimated that ethanol from switchgrass averaged 94% lower GHG than from gasoline. For reasons of efficiency of petroleum use and GHG emissions, Farrell et al. (2006) suggest biofuels will require cellulosic technology.

Challenges of bioenergy crop production arise when determining crop production location. As population continues to increase, more crop yield will need to be achieved to meet dietary needs. Between the years of 1982 and

1997, 4.5 million hectares of cropland were converted to urban land uses (Greene and Stager, 2001). In 2002, U.S. Department of Agriculture estimated 176,700,000 hectares in the U.S. were cropped, down from 180,200,000 hectares in 1997. In the five year period between 1997 and 2002, 4.5 million hectares of agricultural land in the U.S. shifted from rural to urban uses (United States Department of Agriculture, 2002). Additionally, the Energy Independence and Security Act of 2007 now requires 36 billion gallons of biofuel to be produced from renewable sources found within the United States by 2022.

Increased yield from production agriculture will need to be achieved on less fertile land base areas as human population expands into area devoted to agriculture and exploration into marginal lands for bioenergy production is necessary. Currently, the allocation of crops for bio-based fuel sources has raised tensions. The food verse fuel debate challenges human ethics whether food crops should be taken out of the food supply and converted to fuel. Third world countries around the world are facing limited food supplies while developed countries convert food into fuel. Crop production on marginal lands can ease competition between acres devoted to bioenergy and food production.

LAND CLASSIFICATIONS

The United States Department of Agriculture has 8 land capability classes for agricultural suitability. The Land Capability Classification is a system of grouping soils primarily on the basis of their ability to produce common cultivated crops and pasture plants without deteriorating soil properties over a long period of time. Capability classes are based primarily on soil type, slope, and drainage.

Classes I and II are classified as prime agricultural land with few limitations that would restrict use. Classes III and IV are capable of producing crops yet there are severe limitations that can include slope, erosion, flooding, low-moisture holding capacity and fertility, salinity or sodium, and adverse climatic conditions. Classes I through IV are considered capable of producing cultivated crops with good management practices including conservation. Classes III and IV are comprised of various land features that make them environmentally sensitive lands available to be enrolled in the Conservation Reserve Program, in which landowners receive governmental aid for preserving environmentally sensitive acres. Class V has restricted use due to a high water table while classes VI and VII are best suited for perennial vegetative species, but may be capable of producing some specialized crops with highly intensive management. Classes VI and VII may need to implement a vegetative cover used to prevent severe erosion because of severe erosion potential. Land capability class VIII soils have limitations which restrict use making soils not suitable for managed vegetative production (Natural Resources Conservation Service, 2009). Primarily, marginal land encompasses soils of III, IV, as well as VI and VII classification.

In the contiguous 48 states in the U.S., 174.6 million hectares are identified as cropland (USDA, 1999) however not all acres available for crop production are cultivated as 7.7 million hectares are left idle. The Conservation Reserve Program (CRP) accounts for 12.1 million hectares (USDA FSA, 1999). Marginal cropping lands can be enrolled in the conservation reserve program authorized by the Food Security Act of 1985, and administered by the Natural

Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA). Landowners receive financial assistance for implementing environmental protection practices including planting grasses, trees, or other conservation cover. The CRP started in part to the 1985 Farm Bill and sets asides environmentally sensitive hectares under 10 to 15 year contracts. Through 2009, 15.9 million hectares are enrolled in the CRP program with acreage dropping to 12.9 million 2010 through 2012 (United States Department of Agriculture, 2008).

All acres should not be converted out of CRP for bioenergy production on marginal lands. Hectares enrolled in buffer strips to protect water quality, classified as wetlands, essential to watershed management, and critical habitat hectares in Wildlife Conservation Priority Areas should not be taken out of CRP. According to Walsh et al. (2003) 6.8 million hectares of the 12.1 million hectares of CRP are available for conversion to growing bioenergy crops for economic reasons including crop prices, costs of inputs, and attainable yields under marginal conditions. Under current legislation, harvest of CRP is prohibited except under emergency conditions and does not make biomass available for bioenergy conversion.

Marginal land is land which is commonly seen as unsuitable for cultivation of arable crops. Maximum or optimum cropland production depends on the growing season environment and the skill of the producer to identify and then eliminate or minimize factors that can reduce yield potential. There are numerous factors affecting crop yield potential. These can be categorized into three main factors including climate, soil, and crop (Havlin et al., 2005).

Worldwide, the dominant stress reducing crop yield and directly correlating to marginal land is plant available water. Water is the primary influencing management factor when determining productivity of agricultural cropping systems (Stone et al., 2002; Jiang and Thelen, 2004). Aridic soil moisture regimes constitute dry conditions for half the growing season. During growing seasons, rainfall is low in most months and levels of evapotranspiration are high, limiting moisture recharge in arid regions (Foth, 1978). Continuous moisture stress accounts for 36.5 million square kilometers in the US which occupies 27.9% of the total available landbase (USDA-ERS, 2003). In northern climates, low temperatures limit yield and comprise 21.8 million square kilometers of the earth's potential landbase. These regions do not accumulate adequate growing degree days (GDD) for most crops such that plant growth and consequently crop yield is limited.

There are four main physical characteristics used to determine the capability of land: soil texture, drainage, slope, and erosion. Soil factors primarily affecting marginality can include low base fertility, low productivity, coarse soil texture, high erodibility, soil and ground water contaminants, and highly disturbed soils. Soil fertility is the status of a soil with respect to its ability to supply essential nutrients for plant growth without having a toxic concentration of any elements (Foth, 1978). Soil productivity is characterized as the ability of a soil to produce an adequate amount of plant growth with optimum management, which includes issues of fertility, drainage, and other environmental factors (Foth, 1978). All productive soils are fertile, however not all fertile soils are productive.

Depending on the range and characteristics of fertility, soils can support plant growth even though land may be termed marginal. Typically, coarse soil texture affects fertility of land bases however soils with high Cation Exchange Capacities can be classified marginal. The Cation Exchange Capacity (CEC) of soil is strongly affected by the nature and amount of clay minerals or organic matter present within a soil. The CEC of soils dictate the nutrient availability of cations soils are able to adsorb and make accessible for plants. High levels of (50-100 meq/100 g) can be associated with organic soils, and clay and clay loam soils (20-50 meq/100 g). Coarse textured soils have substantially lower CEC values (3-5 meq/100 g) and can be classified as marginal due to low nutrient availability (Havlin et al., 2005).

Soil erosion, which is dependent on soil type and slope, can determine marginality. Soil erosion occurs when soil is removed through the action of wind and water at a greater rate than it is formed. Erodibilty of soil is influenced primarily by soil structure specifically by the proportion, size, and bulk density of the erodible soil particles as well as climate and topography (Havlin et al., 2005). Erodibility is prevalent on land capability classes of III and IV as well as VI-VIII. Erosion is higher on land with greater than 6% slope. Erosion removes soil horizons O and A consisting of organic soil material and mineral soil material, which is typically nutrient laden. The O and A horizons are zones in which roots permeate most frequently. Erosion is a natural process of weathering, yet accelerated erosion occurring more rapidly than by normal, natural, geological erosion is detrimental for nutrient availability and optimal plant growth. Tolerable soil loss due to erosion for sustainability must be below 11.2 t ha^{-1} as it takes 30 years to form one inch of topsoil in Michigan (Havlin et al., 2005).

Other examples of marginal soils can include climatic variables. Climatic factors are dependent on geography and can include shortened growing seasons and low precipitation. Growing Degree Days (GDD) track crop maturity and is calculated using the average of daily high and low temperatures and subtracting a base temperature of 10°C. Locations receiving more GDD have increased potential to support crop growth and to achieve higher yield totals (Swanson and Wilhelm, 1996). Locations with shortened growing seasons accumulate minimal GDD. Precipitation is location dependent and vital for crop growth. A location may accumulate high GDD however if rainfall is limited, the location will still be considered marginal.

There are also additional acres of public and privately owned marginal land which are idle and not enrolled in the CRP can support growth of bioenergy crops. Brownfields and Superfund sites are industrial areas that have contaminated soils and groundwater from past chemical contamination and abandoned hazardous waste, but hold value for economic development or production agriculture if the pollutant is controlled and removed (Licht and Isebrands, 2004). Total acreage designated with superfund or brownfield status is unknown as new locations are continuously discovered. In June 2008, 68 Superfund sites were identified in Michigan by the Environmental Protection

Agency comprising a land area of approximately 2,000 hectares. An additional 3,645 brownfields were identified with acreage unknown (Environmental Protection Agency, 2008). Site areas range from city blocks to hundreds of acres. These lands are not enrolled in production agriculture systems and depending on composition could be utilized for bioenergy crop production. Superfund and brownfield sites are regulated to preclude food crop production, but conversion to energy sources is acceptable (Environmental Protection Agency, 2004). Crops cultivated in areas of known pollution are acceptable sources of biomass for bioenergy (Licht and Isebrands, 2004) and may prove to phytoremediate an area as some plants are better for taking up heavy metals or volatile organics (Westphal and Isebrands, 2001). A heterogeneous environment suggested by Lafortezza et al. (2004) is an approach which optimizes biomass and promotes ecological concepts. Plants take up essentially all nutrients as water soluble compounds through the roots or foliage. Thus, for uptake to occur, contaminants must reach the plant through water in the root zone (Licht et al., 2001).

Fallow agricultural fields are also potential acreage that can be used to cultivate bioenergy crops. In 2007, 2.7 million hectares in Michigan were devoted to production agriculture. According to the Land Policy Institute at Michigan State University, 4.6 million additional hectares are potentially available for production agriculture in Michigan. These lands are not currently cropped, pastured, forested, or wetlands and not currently under development (Land Policy Institute, MSU, 2007). While all available acres should not be used for production agriculture for reasons of habitat preservation, naturalized acres, and sensitive acreage, Michigan producers could use a portion of the available land for bioenergy production. Ceotto (2007) warns of meat and milk markets suffering if marginal grazing lands are transitioned to bioenergy production. Idle land, whether it is a site with low fertility or contaminated soil to produce a beneficial feedstock is an efficient land use strategy.

The utility of using marginal land to produce bioenergy crops on a sustainable basis will depend upon economics and environmental practicality and profitability. Keeping the cost of biofuels low will stimulate consumers to seek alternative fuels and perhaps the environmental implications will keep consumers supportive of a renewable approach. Additionally, incorporation of cap and trading of carbon and carbon tax legislation may make biofuels economical for consumers and producers alike. Information on production amendments, soil structure and characteristics, site accessibility for field scale farm equipment, public perception and environmental ramifications is required to assess the long-term sustainability of biofuels as well as production of biofuel crops on marginally productive soils (Gleeson, 2007).

ENERGY

Daily, more than 20 million barrels of petroleum were consumed in the United States (Organization of Petroleum Exporting Countries, 2007). Approximately 182,000 Mg of carbon dioxide was emitted daily due to 2007 petroleum consumption. Petroleum has been utilized due to BTU efficiency and ease of conversion to energy. Cost and environmental degradation has spurred bioenergy interest as well as published net energy gain of corn ethanol and biodiesel at 25 and 93% (Hill et al., 2006).

Solar radiation striking the earth on an annual basis is equivalent to 178,000 terawatts, which equates to 15,000 times that of current global energy consumption (Food and Agriculture Organization of the United Nations, 1997). Most plants and all field crops are photoautotrophic meaning they are able to synthesize food directly from inorganic compounds using light energy. Plants convert light into chemical energy with a 6% maximum photosynthetic efficiency. Photosynthetic efficiency can vary with the frequency of the light being converted, light intensity, temperature and proportion of CO_2 in atmosphere (Zhu, 2008). Using crops for bioenergy production, sunlight is used to grow biomass. Conversion of biomass into fuel and consumption of biofuel is, in theory, the combustion of sunlight. Biofuel crops are renewable and protective of the environment when sustainable methods are employed to manage, harvest and process the crops.

In recent years, a new round of enthusiasm in biomass and bioenergy has been initiated with the recognition that the global crude oil reserve is finite, and its depletion is occurring much faster than previously predicted. In addition, the environmental deterioration resulting from the over consumption of petroleum derived products, especially transportation fuels, is threatening environmental sustainability. Using bioenergy feedstocks as an energy source captured and harvested from solar energy is environmentally sustainable.

CROP CONVERSION TO BIOENERGY

Plants have provided food, feed, and fiber for the world. Converting grain and biomass efficiently to deliver a liquid fuel source has not been commercialized. Many conversion systems have been investigated. Fermentation and transesterification have been used to convert starch crops, biomass, and oilseeds into a fuel source.

Corn grain fermentation has occurred throughout world development. Historically, corn was fermented to create an alcohol. The U.S. saw potential for the use of ethanol as a renewable fuel source due to the fuel crisis of the 1970's. The widely used milling process to convert corn grain starch to ethanol requires three days for the fermentation process (Solomon et al., 2007).

Lignocellulosic or cellulosic ethanol production converts plant materials into sugars and then ferments the sugars into ethanol. Lignocellulosics are comprised of three primary constituents: lignin, cellulose and hemi-cellulose. Lignin chemistry is close to that of low rank coal. It has a high heating value and usually is regarded as a fuel resource, however is not a source of ethanol. Hemi-cellulose and cellulose are long chain polymers of five-carbon sugars (pentoses) and six carbon sugars (hexoses). Hemi-cellulose is mostly a polymer of xylose, while cellulose is almost entirely a polymer of glucose. The bonds linking the sugar monomers together in the hemi-cellulose and cellulose polymers can be chemically broken by hydrolysis. Following hydrolysis, the sugars can be processed to produce ethanol or other products (Kaylen et al., 2000). High quality ethanol feedstock has zero nitrogen content and is high in cellulose.

Nitrogen reduces the conversion efficiency of fuel into energy and can become an air pollutant after combustion. Therefore, zero or low nitrogen fertilizer applications and a single yearly harvest after the plants have died back fully in the winter produce the best feedstock as well as the highest amount of above ground biomass for ethanol production (Westphal and Isebrands, 2001). Problems arising with cellulosic ethanol stems from conversion economics (Lynd et al., 1991), transportation and storage bottlenecks (Lofstedt, 1996), and producer agronomic adoption. As of 2007 there is no market for switchgrass as an energy crop (Epplin et al., 2007).

Ethanol has gained support as the US Environmental Protection Agency (EPA) has shown interest in making gasoline blends more environmentally friendly. In the 1980's, the EPA started to phase out leaded gasoline. In attempts to find another octane booster and volume extender, ethanol was used in the blend. The rapid growth of the ethanol industry can be attributed to phasing out the additive methyl-tertiary-butyl ether (MTBE) (Solomon et al., 2007) and as research indicates ethanol is relatively water soluble and MTBE is potentially carcinogenic (Belpoggi et al., 1995).

Corn based ethanol has some important potentially negative environmental impacts. Increased soil erosion, loss of biodiversity, and higher volatile organic compound and NO_x pollution are all hazards of agronomic crop production (Pimental and Patzek, 2005). By employing marginal lands and conservation practices, these risks can be minimized. Corn based ethanol, provides a positive energy return on investment and a 10-15 percent reduction in

CO_2 emissions (Farrell et al., 2006; Solomon, 1980; Shapouri et al., 2002; Hammerschlag, 2006).

Biodiesel or fatty acid methyl esters (FAME) results from the process of using transesterification to turn vegetable oils into esters. Using an alkaline catalyst, vegetable oil is separated into respective fatty acid chains and into alkyl esters. The process yields methyl esters and glycerin (Ma and Hanna, 1999). Five fatty acids are produced in biodiesel production including; palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2) and linolenic acid (C18:3). Among these, palmitic and stearic have saturated structures, which are stable during storage and have higher melting points (62 °C and 69.3 °C). While saturated fatty acids are very useful in improving food taste, saturated fatty acids in biodiesel contribute to cold flow issues associated with the fuel. The unsaturated fatty acids, such as oleic (13.4 °C), linoleic (-5 °C) and linolenic (-11.3 °C), have lower melting points and have more unstable properties. In the biodiesel as well as food industry, optimizing oleic fatty acid is most ideal as the fatty acid has a relatively lower melting point than saturated fatty acids and longer shelf life than polyunsaturated fatty acids (Dardanelli et al., 2006; Piper and Boote, 1999; Primomo et al., 2002; Wilcox and Cavins, 1992).

POTENTIAL BIOENERGY COMMODITIES

National energy demands may possibly be met utilizing domestic commodities. Biodiesel and ethanol can be produced from current food crops as well as biomass. Three oil seed crops including soybean, canola, and sunflower can be used to derive biodiesel while corn grain and switchgrass biomass are candidates for ethanol production. Biodiesel, derived from triglycerides by transesterification with methanol, has attracted considerable attention as a renewable, biodegradable, and nontoxic fuel. Ethanol or ethyl alcohol is made from the fermentation of sugar which can be found in the starch of corn grain or cellulose within cell walls of all living plants.

No ideal bioenergy crop has yet to be identified. Raghu et al. (2006) outlined characteristics of ideal ecological traits of bio-energy crops. Characteristics include C_4 photosynthesis, long canopy duration, perennial lifecycle, no known pests or diseases, rapid growth in the spring to outcompete weeds, seed sterility, partitioning nutrients to below ground components in the fall, high water use efficiency, and most importantly high fuel yields per area. According to Raghu et al. (2006) outlined ecological traits, tended to favor a cellulosic ethanol crop for use in bio-energy production. Marginal lands have the ability to support growth of all potential bioenergy crops.

CORN

Corn grain (*Zea mays* ssp. *mays*) in 2008, is the current crop used to produce ethanol in the U.S. Corn is a C_4 warm weather annual grass which was domesticated in Mesoamerica. Prior to domestication, the wild grass was native to Mexico. The oldest carbon dated corn is believed to be cultivated around 5000 B.C. The record originated in the Valley of Tehuacan in Mexico (Magness et al., 1971). The crop has been manipulated by humans through hybridization to achieve higher grain and biomass yields.

Corn is a high yielding C_4 grass which conducts photosynthesis efficiently due to a CO_2 concentrating mechanism that mitigates or eliminates photorespiratory carbon loss (Specht, et al. 1999). This pathway allows C_4 grasses to withstand periods of water stress and high temperatures (Kemp and Williams, 1980). Stresses of moisture availability and temperature can be intensified under marginal conditions.

Corn grain can be classified into five categories consisting of dent, flint, flour, pop, and waxy corn (Smith, 1995). Dent corn is the corn that is primarily cultivated for food, feed, fiber, and fuel use and encompasses the majority of acres in the United States. The endosperm of dent corn, which consists of starches, is vital for seedling growth and is utilized by the ethanol production industry. The endosperm accounts for about 82% of kernel dry weight and is the source of energy and protein for the germinating seed. A non-fermentable portion, the germ, is the embryo from which a new corn plant develops. About 25 percent of the germ is corn oil which is high in polyunsaturated fats which can be utilized for biodiesel production. The pericap or bran protects the seed before germination and preserves nutrient value in the kernel. After fermentation, distillers grain (wet or dry), used for animal rations, consists of the germ and bran (National Corn Growers Association, 2007). Whole grain composition totals 72% starch and 3.8% oil.

Corn yields and subsequently energy yields have benefited from advancements and improvements in production agriculture. Corn yields in the United States have increased over the last 100 years as 1908 yield totals averaged 1.7 Mg ha^{-1} while in 2008 totals averaged 9.7 Mg ha^{-1} (United States Department of Agriculture, National Agriculture Statistics Service, 2008). Changes in national averages of corn yield involves many variables including the use of hybrids, increased fertilizer use, longer seed filling periods, tolerance to high plant populations, improved plant greening characteristics during seed filling, more upright leaves, decreases in seed protein concentration (Duvick, 2005), and increased stress tolerance (Tollenaar and Wu, 1999). Management practices also contribute to higher yield. Higher plant populations (Duvick, 2005), rates of fertilizer, especially nitrogen, introduction of herbicides and improved weed control, earlier planting date, and narrower rows (Troyer, 2004; Widdicombe and Thelen, 2002) have all increased corn yield. Additionally, herbicide tolerant crops have increased corn yields by improved weed control and soil water conversion due to reducing tillage requirements. Under marginal conditions, crop stresses will be amplified and despite crop improvements, yield totals may be negatively affected.

Corn requires a high investment of inputs to maximize grain yield and economic return. Nitrogen significantly affects yield of corn grain. In Michigan, nitrogen amendments employing the Maximum Return To Nitrogen concept should total approximately 112 kg N ha^{-1}. With the development of new hybrids employing nitrogen efficiency, nitrogen recommendations have decreased 0.5-0.7 kilograms of nitrogen per hectare, equating to each bushel requiring approximately 0.9 kg N (Warncke, 2008). These inputs have the potential to limit economic return especially on marginal land where lower yields may make corn yields cost prohibitive.

Planting population is vital when sowing a corn grain crop for optimum fuel return. Corn yield and ethanol yield responds significantly to total plant density. Sarlangue et al. (2007) found optimum plant density to range between 10.3-13.7 plants m^{-2} due to biomass plasticity and reproductive partitioning. Yield response to plant density is greatest for shorter season hybrids, intermediate for medium duration, and lowest for full season hybrids (Widdicombe and Thelen, 2002). At low plant density, short-season hybrids intercept less radiation and produce less biomass than full-season hybrids. Planting populations will reduce water availability in soils and particularly in marginal soils in which water availability is a concern. Higher populations will result in higher grain yield; however marginal land may not be capable of providing adequate water to support high populations.

Total energy yield of corn grain ethanol has been widely debated. On average, 25.4 kg of corn will yield 10.6 liters of ethanol, 8.2 kg dried distillers grain and 8.2 kg CO_2 (Thelen, personal communication). Pimentel and Patzek (2005) found 29% more fossil energy was being used to produce ethanol than it produced. Since release, this finding has been disputed and discounted by many (Kavanagh, 2006). Other studies found starch based ethanol produced from corn grain yields 25% more energy than invested (Hill et al., 2006) and a total net energy ratio of 1.38:1 (Lorenz and Morris, 1995), respectively.

Controversy surrounds the collection of crop residues particularly corn stover for conversion into bio-based fuels. Sustainable energy production from crop residues must take into consideration that residue removal could increase erosion, reduce crop productivity, and deplete soil carbon and nutrients. According to Graham et al. (2007) approximately 30% of stover could be removed for energy production in given counties in the Midwest. Removal of 30% is based solely on erosion control and does not take into consideration the necessity to maintain or enhance soil organic matter and tilth. Soil moisture and nutrient replacement are two more major concerns of residue removal amplified in marginal areas as all stover must be returned to the field to maintain soil moisture for the next crop (Wilhelm et al., 2004).

SOYBEAN

Soybean (*Glycine Max* (L.) Merr.) in 2008, is the current crop used to produce biodiesel in the U.S. Soybean is native of East Asia. The soybean was introduced as a forage crop in North America in 1765. In 1908, 20,000 hectares were grown for forage production (Probst and Judd, 1973). Soybean was not a major grain crop in the United States until the 1920's (Hymowitz and Harlan, 1983). Production statistics were first reported in 1924 when the average national yield was 0.74 t ha^{-1}. In 2008, 22.9 million hectares were planted and yields averaged 2.69 t ha^{-1} (United States Department of Agriculture, National Agriculture Statistics Service, 2008), however, in recent years national yield data suggest soybean yields are showing plateau under known agronomic techniques (Nafziger, 2004).

Soybean is a leguminous crop. Soybean root nodules containing symbiotic *Rhizobium* bacteria reduce N_2 from the atmosphere and convert to NH_3 which can be utilized by the plant (Phillips, 1980). In the symbiotic relationship *Rhizobium* bacteria supply the soybean with a nitrogen source while *Rhizobium* gains carbohydrates (Hoeft et al., 2000). Soybeans provide 33.7 kg N ha^{-1} for the following crop (Warncke et al., 2004) and in the U.S. supply 5.7 Tg N annually (Herridge et al., 2008). Under marginal land conditions, the production of N for subsequent crops is positive. A rotational crop, planted following a soybean crop, will benefit from additional N provided by soybean. Leguminous crops such as soybeans will lower the inputs needed in marginal land rotations which impacts the cropping system by increasing economic returns.

Soybean is a legume with a C_3 carbon fixation photorespiratory pathway. Carbon losses due to C_3 biology substantially reduce photosynthetic output particularly under warmer temperatures and high water stress conditions (Specht et al., 1999). The reduced photosynthetic output will negatively affect crop yield under periods of crop stress. Marginal land crop stresses of water availability, high temperatures, low fertility and erosion may increase negative responses which would limit the utility of soybean as a bioenergy crop on marginal lands.

Soybean has been cultivated traditionally as a protein crop used for livestock feed. Livestock production benefits from soybean attributes as soybean seed is comprised of approximately 40% protein, 25% carbohydrates, and 20% oil. Poultry and swine consume a majority of the crop at 54 and 26% (American Soybean Association, 2007). Domestic use of soybean, though low in percentage, is dominated by frying oils, as a component of margarine and salad dressing, and in the production of inks, paints, and cosmetics (Sheaffer and Moncada, 2008).

Changes and successes of the soybean used as a grain crop include longer seed filling periods (Gay et al., 1980) and decreased lodging and often shorter plants (Specht and Williams, 1984). In some cultivars, seed protein decreases with increases in seed oil concentration (Morrison et al., 1999) have negatively influenced the United States soybean export market. Soybean grain yields have also benefited from narrow rows (Bullock et al., 1998). Many credit earlier planting, adoption of conservation tillage techniques, and reductions in harvest losses for increasing yield (Heatherly and Elmore, 2004). Glyphosate [N-(phosphonylmethyl)-glycine)] resistant soybean used with glyphosate in agronomic systems enables a post herbicide application program which kills a wide range of weed species without reducing yields (Nelson and Renner, 1999) and reduces tillage requirements vital in conserving soil moisture. Marginal land production will benefit from recent advances in soybean agronomy.

Soybean oil and fatty acid methyl esters (FAME) are produced by transesterification of soybean. Total oil content in soybean averages approximately 20 percent oil per volume dependent on maturity zone (Piper and Boote, 1999). The quality of soybean oil depends upon the fatty acid methyl ester (FAME) profile of five major fatty acids (Primomo, 2002). The five major FAME comprise over 98% of the fatty acids in soybean oil (Canakci and Gerpen, 2001; Dubois et al., 2007). On average FAME of soybean oil consists of (g kg^{-1})

linoleic 540, stearic 40, linolenic 70, palmitic 110, oleic 240 weight per volume of oil respectively (Primomo, 2002). In the food and biodiesel industry, optimizing oleic acid is ideal as it has a relatively lower melting point than the saturated fatty acids (palmitic and stearic) and longer shelf life than polyunsaturated fatty acids (linoleic and linolenic).

FAME quantities are dependent on environmental conditions (Primomo, 2002). FAME quantities decrease when subjected to environmental stresses such as drought and temperature (Dombos and Mullen, 1992; Wolf et al.,1982). Linolenic and linoleic acid decreased and oleic acid increased as the temperature increased while palmitic and stearic acids remained unchanged. Additionally, Karaaslan found sowing date affected fatty acid composition (2008). A study performed by Howell and Collins (1957), found fatty acid levels were not affected by environmental factors such as photoperiod, light intensity and quality, nitrogen, phosphorus, potassium, and sulfur nutrition, or the addition of manure or plant residues. Under marginal land conditions, FAME profiles are likely to show variation. Marginal land conditions are not ideal for soybean production due to environmental stresses and are likely to influence soy-diesel components.

The esters of soybean oil have similar physical properties, such as viscosity, cetane number, and energy content to No. 2 diesel fuel, while reducing carbon, sulfur and nitrogen exhaust emissions (Knothe and Dunn, 2001). 27.2 kg of soybean grain yields 1.7 liters of soybean oil (Thelen, personal communication). Co-products of soy-diesel per 27.2 kg of grain include 21.8 kg of soybean meal which can be used as a protein source in livestock rations as well as 0.5 kg of glycerin which can be used to produce soaps and cosmetics. Soybean oil has potential for use as an oil alternative however it has some limitations for use in direct-injection engines due to high viscosity, low volatility, and the polyunsaturated character of the triglycerides (Schwab et al., 1988). In 2005, it was reported that 260 million liters of soybean oil was converted to biodiesel (Urbanchuk, 2006) requiring (based on national yield data) 8.5% of the total US yield (United States Department of Agriculture, National Agriculture Statistics Service, 2008). Increasing soybean production on marginal lands could increase national total yields as well as lower the percentage of commodity allocated for fuel conversion.

CANOLA

Agronomic production of rapeseed can be traced back 3,000 years ago to India. The crop was first cultivated as an oil source for lamps and later was used for cooking oil (Hougen and Stefansson, 1983). The name canola (*Brassica napus* L. var. *napus*), adopted in 1979, was used to describe a rapeseed cultivar with "double low" or less than 2% erucic acid. In 1985, canola and rapeseed were separated into two distinct species (Shahidi, 1990). In 2007, the United States harvested 2.9 million hectares and averaged 1,401 kg ha^{-1} totaling 4,063 million kilograms. In 2008, United States acreage decreased to 2.4 million hectares while yield increased to 1,697 kg ha^{-1} totaling 4,073 million kilograms (United States Department of Agriculture, National Agriculture Statistics Service, 2008).

Canola is a C_3 oilseed crop that can be planted in the fall in the southern U.S. and southern Europe, or spring in the northern US, Canada, and northern Europe (Gunstone, 2004). Reduced photosynthetic output will negatively affect crop yield under periods of crop stress. Soil conditions for optimum canola yield include medium textured, well drained soils. Soil pH between 6.0 and 7.0 is optimal, and yields may be reduced significantly if pH is below 5.5 (Boyles et al., 2008). Fall canola requires approximately 40.6 to 45.8 cm of precipitation through the growing season while spring varieties require 20.3 to 21.1 cm of precipitation (Oplinger, 1989).

Canola is a candidate for marginal land situations due to the deep penetrating taproot which can breakup hardpans and improve soil structure (Gunston, 2004). Increases in canola production can also be linked to growers concern of Fusarium head blight (*Fusarium gramenearum* Schwabe) and other disease infestations causing low yields in competing cereal crops to which canola is not affected (Hanson et al., 2001) in addition to increased canola oil use as a healthy cooking oil and biodiesel feedstock. Additionally, field machinery used in other cereal crop production is similar making transition to canola production unproblematic.

Like other primary cash crops, canola has been subjected to genetic modification to increase agronomic productivity. The leading alteration has been herbicide tolerance, mainly glyphosate resistance. Research conducted by Brookes and Barfoot (2006) indicates use of glyphosate resistant canola contributed to 6% higher canola yield in the US and 11% in Canada.

Additionally, the convenience of controlling a wide spectrum of weeds with a single post emergence application and increase economic return explain the rapid adoption of this technology (Harker et al., 2000). By the use of glyphosate resistant canola, pest pressure is not amplified as fleas beetles, cabbage seedpod weevil, and lygus bugs do not exhibit a preference to invade and damage conventional over herbicide tolerant canola (Caramo and Blackshaw, 2007). Herbicide resistance reduces tillage necessary for optimum grain yield and conserves critical soil moisture essential for marginal land environments.

One potential problem of genetically modified canola hybrids was addressed by Hansen et al. (2001). Research indicated canola can show introgression under natural conditions from *B. napus* to *B. rapa*. Flax (*Linum usitatissimum* L.) has the potential to hybridize transgenic traits with weedy and wild relatives (Jhala, 2008) and pollen flow from herbicide resistant canola cultivars may occur to weedy pests and unaltered canola genetics.

Canola oil conventionally is used as cooking oil. Health benefits of low saturated fats (7%), high levels of monounsaturates (61%), no trans fat, and a good source of polyunsaturated omega-3 fatty acid (Canola Council of Canada, 2008) which has been linked to lower the risk of coronary heart disease (Kris-Etherton, 2002) has prompted agronomic production.

Canola seed content averages 40% oil and 23% protein (Oplinger, 1989). Canola oil is highly suitable for production of quality biodiesel as 60% of the oil is comprised of monounsaturated oleic acid which demonstrates good stability and winter operability. Canola is the biggest source of feedstock for biodiesel production in the world and has become more attractive as rapeseed breeders have improved yield levels of 2.9 ton oil ha^{-1} in Northern Germany (Puppan, 2002). In the US, canola can yield 11.0 liters per 22.7 kg and a hectare can yield 1122 liters (Thelen, personal communication). Rapeseed contributes 84% of the raw material in the world used for production of biodiesel production while soybean and sunflower accounted for 1 and 13%, respectively (Korbitz, 2000).

SUNFLOWER

Sunflower (*Helianthus annuus*) is native to North America. Archeological evidence suggests Native American tribes cultivated sunflower for grain in present day Arizona and New Mexico around 3000 B.C. The crop was cultivated for commercialization in Russia and in 1880; a cultivar named 'Mammoth Russian' was available. The crop originally was used to augment poultry dietary rations and in 1926 sunflower seed was crushed for oil. In the 1970s, hybridization of sunflower began and traits providing additional yield and oil enhancement as well as disease resistance were incorporated (Schneiter, 1997).

Acreage of sunflower in the United States in 2007 reached 970,000 hectares and averaged 1,610 kg ha^{-1} accumulating a total crop of 8,050 million kilograms. In 2008, the number of acres increased to 5.9 million hectares as average yield increased to 1,623 kg ha^{-1} totaling 9,576 million kilograms (United States Department of Agriculture, National Agriculture Statistics Service, 2008).

Sunflower is a C_3 oil seed which planted in the spring. Reduced photosynthetic output due to C_3 pathways can negatively affect crop yield under periods of crop stress. The stem can grow as high as 3 meters and the flower head can reach 30 cm diameter. Sunflower has a well developed, deeply penetrating root system, which following establishment can withstand droughty conditions but depletes soil water more than sorghum, corn, and canola (Stone et al., 2002; Merrill et al., 2007). The critical growth period for sunflower grain yield is the R3 stage when sensitivity to environmental conditions is prevailing. (Schneiter, 1997). In this stage, sunflower is in the reproductive stage before flowering in which the immature bud elongates more than 2.0 cm above the nearest leaf (Schneiter and Miller, 1981).

Sunflower is typically cultivated for direct human consumption. Confection sunflower seeds are normally black with white stripes and are approximately five eighths of an inch long. The heavy hull accounts for approximately half the weight of the seed and is loosely fixed to the kernel inside to enhance consumption. Oil sunflower seeds are black and much smaller than confection. Oil seeds have been bred to enhance oil content (National Sunflower Association, 2008).

As with oil seeds, fatty acid profiles determine oil conversion efficiency. Izquierdo et al. (2006) determined the critical period for fatty acid composition in sunflower at 100 to 300 degree days after flowering. Sunflower oil contains approximately 90% unsaturated fatty acids, combined oleic and linoleic, and 10% saturated fatty acids, palmitic and stearic (Steer and Seiler, 1990; Izquierdo et al., 2006). Sunflower oil does not contain linolenic fatty acids. Oleic acid content in sunflower is cultivar dependent. Traditional sunflower has an oleic acid content of 14 to 39%, mid-oleic acid sunflower of 42–72% oleic acid, marketed as

NuSun, Mycogen, Breckenridge, MN, and high-oleic acid sunflower containing 75–91% oleic acid (Hajimahmoodi et al., 2005).

Fatty acid levels are quite variable as levels are known to be affected by night temperatures during the grain filling period, cultivar, environmental stress, and fertility (Zheljazkov et al., 2008). Modeling performed by Izquierdo et al. (2006) found the relationship between oleic acid and night time temperature was linear up to the maximum level reached at 22.6° C. In growth chamber experiments, oleic acid ranged from 39 to 52% among differing temperature treatments. Increasing night temperature from 20° to 23° C resulted in a higher oleic and lower linoleic acid concentration. Palmitic acid concentration was highest at the 28° and 20° C temperature regime while stearic acid concentration was not temperature dependent (Izquierdo et al., 2006). Research conducted by Zheljazkov et al. (2008) found that increased N fertilization reduced oil concentration 4% in sunflower. However, more seed was produced which subsequently increased oil yield per acre. Oleic, the major fatty acid constituent of sunflower oil, responded a positive 4.3% with additional N amendments. Oleic acid response to N under marginal land conditions can be problematic as it is closely tied to N fertility while temperatures do not appear to be detrimental.

Currently, sunflower oil is produced primarily for human consumption purposes. Oleic acid and saturated fatty acids are desirable in frying, because unlike polyunsaturated fatty acids, do not need to be hydrogenated before use. Sunflower oils have high stability in frying applications and have a long shelf life, which makes the oil valuable. Nearly 3 billion kg of sunflower per year is marketed for use in frying oils (Zheljazkov et al., 2008). Additionally, sunflower has protein levels of 26% and is the fourth highest source of protein supplement behind soybean, cottonseed, and canola meals (Herridge, 2008).

Sunflower is able to produce 5.7 liters of biodiesel per 12.2 kg. Yield of sunflower can produce 720 liters hectare (Thelen, personal communication). The cake co-product can also be used as a component of cattle rations. Biodiesel production from sunflower will have to compete with the export seed and crude oil market which may place a higher value on the seed and oil versus its use as a biodiesel feedstock. Additionally, costs associated with processing and refining significantly increases the cost of the oil as it applies to the transesterification process as a biodiesel feedstock cost. Price increases may make biodiesel derived from sunflower cost prohibitive (Nelson et al., 1994).

SWITCHGRASS

Switchgrass (*Panicum virgatum* L.) is a warm season perennial grass native to the tallgrass prairies once found throughout the eastern two-thirds of the United States before Europeans arrived (Hitchcock, 1935). It was widely considered an obstacle to progress in agriculture and in the 19th century, the famous "sodbusters" cleared the land of tall grass prairies. Switchgrass has a relatively stiff stem, which the name suggests, and has been used by Native Americans before European arrival. Switchgrass as a crop has primarily been used as a forage and since 1980 has it been considered an option for bioenergy (Parrish and Fike, 2005).

As a C_4 carbon fixation plant, switchgrass can fix carbon by multiple metabolic pathways with high water use efficiency. In general C_4 plants will produce 30% more biomass per unit of water than other species. Grasses with C_4 metabolism are also better adapted to arid production areas where moisture is limited (Moss et al., 1969).

Switchgrass is classified as a lignocellulosic crop. Its cell wall is high in cellulose and lignin that can be used either by direct burning to produce electricity or heat or digested to sugars, which can be fermented to produce ethanol. As a perennial crop, switchgrass can survive less intensive management and grow better on poorer quality, marginal lands than annual row crops such as corn or soybean. The economic return of production to ethanol from lignocellulosic sources surpasses that of annual crops in intensely managed production systems (McLaughlin and Kszos, 2005).

The majority of land for perennial grass production is projected to come from the reallocation of existing cropland and land currently enrolled in the Conservation Reserve Program (CRP) (Schmer et al., 2007). Switchgrass has been used extensively on acreages set aside in CRP to minimize erosion (Jewett et al., 1996; Moser and Vogel, 1995). According to Walsh et al. (2003) nearly 17 million ha^{-1} of cropped, idle, pasture, and CRP lands could be converted to switchgrass production for economic reasons including crop prices, costs of inputs, and attainable yields resulting in an annual production level of 155 million Mg. Switchgrass is most productive on moderately-well to well drained soils on medium fertility and at a soil pH range of 5.5 to 7.0. However, seedlings are quite tolerant of marginal and acid soils (Bona and Belesky, 1992) and switchgrass roots have been reported to grow at pH 3.7 (Stucky et al., 1980). Since switchgrass is a polymorphic species with two distinct ecotypes, lowland and upland (Brunken and Estes, 1975) plants are able to withstand varying conditions. Lowland types are found on floodplains and are able to survive short-term flooding while upland types occur in upland areas which may be droughty.

Switchgrass has a dense canopy and extensive root system which reduces erosion from wind and water (Ichizen et al., 2005). The dense canopy following establishment also suppresses weed populations (United States Department of Agriculture, 2000). Variations in switchgrass growth and yield can best be predicted by accumulated growing degree days (Mitchell et al., 2001). As a result, switchgrass can produce a high yield of biomass across a wide range of climatic scenarios and is suitable for growth on marginal, highly erodible droughty soils (Casler et al., 2007).

Switchgrass has been shown to facilitate the breakdown or removal of soil contaminants though bioremediation. Contaminants including herbicides (Belden and Coats, 2004) and polychlorinated biphenyls (Dzantor et al., 2000) are a few contaminants removed by the native grass. Other bioenergy feedstocks such as poplar and willow have been used for bioremediation and are environmentally acceptable sources of biomass for bioenergy (Vassilev et al., 2004). Bioremediation properties may prove to be vital for switchgrass success as a bioenergy crop on marginal lands.

Seeding rates of switchgrass are vital for stand success. Limitations to switchgrass production include seed which has increased dormancy and is slow to establish. Additionally, no herbicides or fungicides are currently labeled for weed and disease control in switchgrass. In a study conducted by Mooney et al. (2008), seeding rates varying from 1.13-5.67 kg did not make a significant difference on switchgrass yield on differing marginal soils in Tennessee. It has been suggested, switchgrass cultivated on marginal land should be seeded at rates of 4.5-6.7 kg ha^{-1} to account for seed dormancy.

Switchgrass grown as an energy crop has potential to reduce atmospheric CO_2 accumulation by replacing fossil fuels and sequestering C (Bransby et al., 1998). Studies performed by Gebhart et al. (1994) found land enrolled in CRP and marginal land as part of a perennial grass system improves C sequestration in comparison with annual row crops and especially at deeper soil depths such as 30-90 cm (Liebig et al, 2004). Ma et al. (2000) found over long term studies, switchgrass stands can increase soil C levels 28-45%. Research conducted by Lemus and Lal (2005) found C sequestration rates ranging from 0.6 to 3.0 Mg C ha^{-1} yr^{-1} in degraded soils.

Switchgrass is a highly productive warm season perennial grass. Yield potential is highly dependent upon latitude as well as the survivability of a switchgrass stand (Casler et al., 2004). Yields of switchgrass are calculated on dry matter content. Switchgrass moisture at harvest should be around 15% or less to facilitate quick baling and transport. Yields lower than 4 Mg ha^{-1} per year were common in the1970s. As the crop has progressed into a bioenergy crop as compared to a forage crop, yield has increased. Today, switchgrass yields will frequently total 10 Mg ha^{-1} per year. Under intense management practices and fertilizer amendments, yields have reached 20 Mg ha^{-1} per year and higher (Parrish and Fike 2005) in research plots however grower yields could be 35-45% lower due to field landscape inconsistencies, and windrowing and baling tasks (Monti et al., 2009). Under management practices with no additional N or manure amendments, yields have reached 9 Mg ha^{-1} (Lee et al., 2007). Varvel et al. (2007) found under marginal conditions, switchgrass compared to corn grain and stover yield, when converted to ethanol, showed no differences in fuel yield using the same production practices and landbase.

Cutting system and timing also affects productivity of switchgrass as a bioenergy crop. Multiple cutting systems have been suggested to increase yield as is done in clover crops. Reynolds et al. (2000) found that a two cut system, an early summer cutting and one following a killing frost, yielded more biomass than a one cut post frost cutting. Conversely, Sanderson et al. (1999) found reduced total seasonal yields as harvest frequency increased. Research conducted by Lee et al. (2007) looked at alternating harvest years. Cutting systems every year yielded more dry matter biomass than an alternate year cutting system. Subsequently, due to seed rain and reduced stress on stand, switchgrass stands were denser in the alternate year systems than compared to the yearly cutting cycle. Casler and Boe (2003) found a mid-August harvest in the north-central USA reduced stand density over time compared with a fall harvest, yet in the Midwest maximum switchgrass yields occurred at this time

(Vogel et al., 2002). Delaying cutting from fall until spring to provide animal cover during the winter decreased yield 40% (Adler et al., 2006). It is vital to leave six inches of stubble following harvest to help trap snow and protect the root crowns from winterkill (Westphal and Isebrands, 2001).

Switchgrass, a native grass covering many ecological niches, is not susceptible to many diseases and pests. It has a wide adaptability to disease and pest pressure which is likely due to high levels of genetic diversity associated with open pollinated reproduction, a deep, strong root system, and efficient C4 physiological metabolism. Smut caused by a fungus *Tilletia maclaganii*, has been identified as a threat to switchgrass yield. Smut is prevalent in low yielding fields having characteristics of premature flowering, stunting, purple pigmentation of glumes, and replacement of seeds by fungal spores (Gravert et al., 2000). Fields with smut infestations greater than 40% yielded less than 30-40% of the expected biomass (Paige Marie Thomsen-Johnson, 2001).

In 2009, switchgrass is not converted commercially to ethanol. Many reports have indicated fuel yield per acre, yet average yield results equate to 8 tons dry matter per acre yielding 273 liters per ton resulting in 5387 liters per hectare (Thelen, personal communication). Cellulosic crops have the potential to yield more fuel than grain based feedstocks, yet are more difficult to process.

CONCERNS OF BIOENERGY CROPS

There are numerous potential bioenergy crops. A single, all purpose bioenergy crop has not been identified. Determining selection for a given region is vital for bioenergy production success. Of the previously identified crops, some characteristics have the capability to be problematic. Canola has the ability to either hybridize or introgress glyphosate resistant genes into unaltered canola or weedy relatives through the same process as flax (*Linum usitatissimum* L.) (Jhala, 2008). Sorghum and sunflower also have the ability for some transgenes to introgress into wild relatives shattercane (*Sorghum bicolor*), Johnsongrass (*Sorghum halepense*) and common sunflower (*Helianthus annuus*) (Stewart et al., 2003). *Sorghum halepense* at the time was deemed a beneficial introduced forage grass which inevitability has become an invasive weed in 16 U.S. states (McWhorter, 1993). Sterility has been bred into several species however work with polyploidy species does not always guarantee sterility (Gray et al.,1991). Additionally, prolific seed production exhibited by species such as switchgrass has the ability to create populations in unintended areas. Seed inputs by Panicum species can range from 10,050 to 500,000 seeds (Vengris, 1975). To help plants conserve energy, most biomass is harvested after senescence in the field which can facilitate dispersal of seed to unintended areas. Bioenergy feedstocks are being selected from taxa that produce highly competitive stands that thrive with minimal human intervention (DiTomaso et al., 2007) and research focusing on invasive characteristics is needed.

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<u>Chapter 2. Use of Regulatory Brownfield Sites for BioEnergy Production</u>

ABSTRACT

Agriculture faces unique challenges as increasing world population places unprecedented demands on food, feed, and energy resources. Agricultural resources are becoming increasingly stretched to meet the demands of both food and fuel production. Marginal land regulated for consumption purposes could be utilized for bioenergy crop production. In 2006-2008, we evaluated corn (*Zea mays* L. ssp. *mays*), soybean (*Glycine Max* (L.) Merr.), canola (*Brassica napus* L. var. *napus*), sunflower (*Helianthus annuus* L.), and switchgrass (*Panicum virgatum* L.) at two sites to determine the highest-yielding crop for bioenergy production. Sites selected for the study included a remediated brownfield site in Rose Township (ROSE), Oakland County, 42° 43'N, 83° 37'W (ROSE) and a historically cropped site at East Lansing (MSU), Ingham County, 42° 41'N, 89° 29'W, serving as the control. Comparisons of biofuel quality components were also conducted. Yield of soybean, sunflower, canola, and switchgrass differed between locations; however, the historically cropped site did not consistently provide higher yields than ROSE. Ethanol yield from corn grain (L/kg) and the total oil yield of oilseed crops was not significantly different ($p<0.05$) between locations. Concentrations of palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) fatty acids differed by location, yet oleic acid concentrations, vital in biodiesel production, across all crops were not significantly different. Total crystalline cellulose levels from switchgrass were higher at MSU compared to ROSE in 2007 yielding 16% more crystalline cellulose; conversely sampling collection process were refined in 2008 showing

no differences between locations. Pollutant scans results indicated detectable PCB presence in soils from ROSE; however, transfer to grain or biomass was not detected. Results suggest that brownfield sites should be explored to increase crop acreage and biomass availability for conversion to bio-based fuel sources.

INTRODUCTION

Energy production from agricultural crops in the United States has become an ethical dilemma (Cairns, 2007). Crops once devoted for food, feed, and fiber production are now allotted to energy production, potentially reducing the amount of commodities available for human consumption. If cultivation of marginal acreage not currently under production was explored to increase bioenergy crop production, the conflict of using consumption crops for energy production would be alleviated (Walsh et al., 2003). One way to diminish the competition is to produce bioenergy feedstock on land deemed unfit for the production of food crops such as superfund and brownfield sites (Environmental Protection Agency, 2004). Brownfield and superfund sites are industrial areas where the soil and water have been contaminated from chemical or abandoned hazardous waste.

Total brownfield acreage in the United States has not been identified. In 2007 in Michigan, the Department of Environmental Quality identified 68 superfund sites with total acreage exceeding 2,025 hectares. An additional 3,645 sites have been identified as polluted with acreage unknown (Michigan Department of Environmental Quality, 2007). In the entire U.S., there are over 500,000 brownfield sites (Reddy et al., 1999). Soil and groundwater from historical industrial dump sites can contain pollutants such as polychlorinated biphenyls (PCBs), polyvinyl chloride (PVCs), heavy metals, petroleum products and various solvents. These materials are persistent in soils and are not easily removed.

Perennial grasses and native vegetation have been used to phytoremediate brownfield sites, however plant material generated from these sites has not been sought for use (Belden and Coats, 2004; Dzantor et al., 2000; Vassilev et al., 2004). In efforts to produce large quantities of grain and biomass to supplement energy needs, agronomic principles will need to be refined to address sustainability of such cropping systems. Additionally, the quality of fuel resulting from brownfield acreage will also need to be evaluated to ensure contaminants are not released during direct combustion.

Studies have been conducted to evaluate switchgrass cultural practices under marginal conditions (Mooney et al., 2005) and to compare corn grain and stover yield with switchgrass yield in marginal environments (Varvel et al., 2008). However, there is little information available on multi-crop comparisons among corn (*Zea mays* ssp. *mays*), soybean (*Glycine Max* (L.) Merr.), canola (*Brassica napus* L. var. *napus*), sunflower (*Helianthus annuus*), and switchgrass (*Panicum virgatum* L.) on marginal soils such as those on remediated brownfield sites. It is currently unknown whether crops grown on various types of brownfields will yield profitable quantities of quality fuel.

In this study we seek to 1) evaluate bioenergy crop yield on a remediated brownfield site; 2) identify the optimum bioenergy crop for that specific brownfield; and 3) analyze fuel derived from brownfield sites and make comparisons to traditional cropping systems. A regulatory brownfield located in Rose Township, MI, that had been subjected to previous remediation under the auspices of the USEPA superfund program was used as the study site.

MATERIALS AND METHODS

Site Description

In 2006, 2007, and 2008 field experiments were conducted at a regulatory brownfield at Rose Township Dump Site (ROSE) in Oakland County, Michigan. A second site on non-contaminated agricultural land was established at the Michigan State University Agronomy Research Farm (MSU) in Ingham County to serve as an experimental check for crop yield and quality analyses. Crops evaluated include: corn, soybean, canola, sunflower, and switchgrass. Site characteristics can be found in Table 2.1.

Table 2.1. Site characteristics of location, elevation, soil type, land capability class, pH, P and K levels.

Site	Location	Elevation	Soil Type	Land Capability Class	pH	P	K
		m				meq	
MSU							
	42° 41'N 89° 29'W	261	Capac Loam (fine-loamy, mixed, mesic, Aeric Ochraqualfs)	II	6.0	3.3	8.1
ROSE							
	42° 43'N 83° 37'W	317	Marlette sandy loam (fine-loamy, mixed, mesic Haplic Glossudalfs)	II	7.6	2.1	4.7

Site history at MSU included a previous crop of soybean in 2005 while at ROSE there was not a previous crop. ROSE was a fallow field undergoing succession and according to site history and soil characteristics, would be deemed unfit for food crop production. The site consists of an upland area which is almost completely surrounded by hydric soils. The pollutants found in soil and groundwater at Rose township before remediation included solvents, paints, polychlorinated biphenyls (PCBs), phthalates, lead battery sludges, chromium, and volatile organic compounds (VOCs) such as toluene, benzene, and trichloroethene, which breaks down into vinyl chloride (USEPA, 1987). Michigan Department of Environmental Quality initiated removal and remediation action at the site in 1980. During 1992, a mobile incinerator was constructed at the site and was used to treat over 16,000 cubic meters (34,500 metric tons) of PCB-bearing surface soils by incineration. In addition to incineration, an air stripping groundwater pump and a soil vapor extraction (SVE) unit was also installed to remove PCBs and VOCs, respectively. In 2006, an independent EPA capture zone analysis, along with data from monitoring wells at the edge of the plume, showed that pollutants were still persistent and complete capture was not occurring (Fayoumi, 2008).

Contaminant Analysis

Soil and grain were extracted for contaminant analysis using accelerated solvent extraction, ASE 200 (Dionex, Sunnyvale, CA). Ten grams of dry grain or soil plus an equal amount of sodium sulfate (Sigma, St. Louis, MO) were placed into an 11 ml extraction cell fitted with a glass fiber filter, (P/N 047017, Dionex, Sunnyvale, CA) and fitted with a stainless steel frit at the outlet. Sodium sulfate was not used in grain sample analysis. The dead volume of the cell was filled with Ottawa sand (S23-3, Fisher Scientific, Pittsburg, PA). The extraction cell was closed and automatically moved into a heatable extraction oven, filled with solvent, and pressure was pressurized to 6900 kPa. Following the extraction period, the extract was drained into a collection vial purged with compressed nitrogen. The extraction temperature was 105°C, with a preheat period of 6 min, and static extraction periods of 5 min with one cycle and a flush volume of 60% using 50% acetone and 50% hexane.

After extraction, the collection vials were weighed to determine extract mass and recapped with undamaged septa. ASE samples were transferred to gas chromatography (GC) vials and analyzed on an Agilent GC 6890 (Agilent, Santa Clara, CA) equipped with a 30 m x 0.32 mm x 0.25 µm Supelco Equity 5 capillary column (Supelco, Bellefonte, PA) and HP 7673 autosampler (Agilent Technologies, Santa Clara, CA). An electron capture detector (GC-ECD) (Agilent Micro ECD, Santa Clara, CA) was used to detect electron-absorbing compounds; parameters included: an increase in oven temperature from 120°C to 300°C at 9°C per minute, injection volume of 1 µl with split ratio 4:1, inlet temperature of 250°C, and a detector temperature of 310°C. Ultra high purity (99.999%) helium was used as a carrier gas at flow of 30 ml/min. Ten representative peaks were chosen based on the fraction of total area and uniqueness in the Aroclor 1248 standard as compared to the Aroclor 1254 standard (Supelco, Bellefonte, PA). The sum of these peaks was taken to represent the total PCB content of the soil and grain samples.

Cultural and Management Practices

At the noncontaminated MSU site, plot preparation included spring chisel plowing prior to planting. Management strategies for ROSE differed from MSU as previous cropping systems required differing management. A glyphosate application on 3 May 2006 followed by controlled burning and shrub removal on 24 May 2006.

Seeding dates, rates, and varieties are shown in Table 2.2. Varieties were selected according to Michigan maturity zones.

Table 2.2. Planting date, seeding rate, and variety selection for MSU and ROSE.

	Date		Rate	Variety
	2007	2008	ha^{-1}	
Corn	May 21	May 13	74,131†	Dekalb 38H66-RR2
Soybean	May 21	May 13	444,785†	Diehl Fields DF8242RR
Canola	May 21	April 30	6.72‡	Dekalb DKL 38-25RR
Sunflower	May 21	May 13	74,131†	Seeds 2000 Charger
Switchgrass	May 21*	-	11.2#	Forage First Forestburg

*Reseeded switchgrass stand

† Seeding rate in seeds ha^{-1}

‡ Seeding rate in kg ha^{-1}

Seeding rate in kg pure live seed ha^{-1}

Planting of annual crops followed in 2007 and 2008 in a canola-corn-soybean-sunflower rotation with switchgrass remaining in dedicated established plots. Switchgrass was originally planted in 2006 and no-till replanted in 2007 due to low populations.

In 2007, corn, soybean, and sunflower were planted with a custom built planter utilizing John Deere row and vacuum units (Deere & Company, Moline, IL) and canola and switchgrass were planted with an Almaco drill (Almaco, Nevada, IA). In 2008, corn, soybean, and sunflower were planted with a custom planter utilizing John Deere row units equipped with MaterMacc (MaterMacc, San Vito al Tagliamento, Italy) metering units while canola was planted with an Almaco drill.

Herbicide labels were followed for application and timing was crop dependent as shown in table 2.3.

Table 2.3. Postemergence herbicide applications and timing.

	Glyphosate	Glufosinate	Atrazine	Quinclorac
		Date (2007, 2008)		
Corn	May 23, May 15	-	-	-
Soybean	May 23, May 15	-	-	-
Canola	May 23, May 15	-	-	-
Sunflower	-	May 24, May 24	-	-
Switchgrass	-	-	May 12, May 10	*, May 10

* No application was made in 2007

Nitrogen soil amendments were side-dressed at rates of 112 kg ha^{-1} in corn and sunflower. Other crops received no fertilization.

Harvest and Handling

In 2006, crops were planted and harvested to establish the rotational system, but yield totals were not recorded. Harvest dates for 2007 and 2008 are presented in Table 2.4.

Table 2.4. Harvest dates at MSU and ROSE.

Crop	Harvest Date			
	MSU		ROSE	
	2007	2008	2007	2008
Corn	Oct. 12	Oct. 29	Oct. 21	†
Soybean	Oct. 11	Oct. 22	Oct. 11	Oct. 23
Sunflower	Sept. 10	Sept. 17	Sept. 11	Sept. 20
Canola	†	July 23	Aug. 22	July 24
Switchgrass	Nov. 1	Oct. 29	Oct. 30	Oct. 29

†Crops not harvested due to wildlife damage.

In 2007, corn and soybean grain yield was determined by whole-plot harvests using a small-plot combine (Massey Ferguson 8XP, AGCO, Batavia, IL), and by flail harvester (Carter Manufacturing Co. Inc., Brookston, IN) for switchgrass. Two sunflower and canola rows, 1 m in length with three replicates per plot, were harvested by hand. In 2008, only subplot areas not affected by wildlife damage were harvested. In corn, 1.5 by 12.9 m was hand-harvested from two areas of each plot. In soybean, 1.1 by 12.9 m was hand-harvested from three areas of each plot. In canola, three areas 1.5 by 12.2 m were swathed (Swift Machine, Swift Current, SK), then threshed (Almaco, Nevada, IA). In sunflower, three areas 1.5 by 1 m were hand-harvested and sunflower heads were threshed (Almaco, Nevada, IA). In switchgrass, three 50.8 by 50.8 cm quadrats were hand-harvested at a cutting height of 7.6 cm from the soil surface. To eliminate potential bias associated with wheel tracks and implement overlap, only the center rows of each planter pass were harvested.

Grain moisture levels were determined using a DICKEY-john GAC 2100 grain analysis computer (DICKEY-john, Auburn, IL). Grain samples were oven-dried at 60°C to 15.5, 13.0, 8.5, and 10.0% storage moisture for corn, soybean, canola, and sunflower, respectively. Switchgrass samples were weighed in the field, oven dried at 100°C for 4 days, and weighed again to determine dry matter content.

Corn Grain Ethanol

Triplicates of 25 g ground corn grain samples were used for ethanol analysis following a gravimetric, 72 h fermentation method described by Lemuz et al. (2004). Each 25 g ground corn sample was mixed with 75 ml deionized water and 27 µl alpha-amylase (9000-85-5, Sigma-Aldrich Inc., Allentown, PA) to break the α1-6 linkage in the starch and form single glucose molecules in an Erlenmeyer flask fitted with a rubber cap and needle vent. The slurry was incubated in a 90°C oven for 90 min with occasional shaking. The slurry temperature was then lowered to 60°C, and the pH was adjusted to 4.1-4.5 with hydrochloric acid (EMD Chemicals Inc. Gibbstown, NJ). The liquefied corn slurry was saccharified and fermented simultaneously by adding 20 µl gluco-amylase (9032-08-0, Sigma-Aldrich Inc.), 5 ml yeast inoculum, and 0.4 ml 1M NH_4SO_4 (EM Science, Gibbstown, NJ). The flask was placed in a 60°C oven for 2 h before it was placed in an incubator shaker at 32°C at 150 rpm for 72 h (Model

C25, New Brunswick Scientific, Edison, NJ). The yeast inoculum was prepared according to Wang et al. (1999). Briefly, active dry yeast (Fleischmann's yeast, Fenton, MO) was dispersed in 99 ml of 0.1% sterile peptone water (DOT Scientific Inc. Burton, MI) and prewarmed at 38°C. The flask with the slurry was weighed together before and after the incubation, and the difference in weight was considered as the mass of CO_2 released during the fermentation. Assuming 100% recovery, total ethanol produced was computed using a 1:1 molar ratio of ethanol to CO_2 and the following conversion:

$$n = ((W1 - W2)/44) \times 46$$

where n is the total ethanol yield in grams, W1 in grams is the weight of the solution before fermentation, W2 in grams is the weight of the solution following fermentation, 44 is the molecular weight of CO_2, and 46 is the molecular weight of ethanol.

Fatty Acid Methyl Esters

Fatty acid methyl ester (FAME) quantities in oil seed crops were determined using a protocol adopted from Hammond (1991). Subsamples of soybean, canola, and sunflower seed were collected at the time of harvest. Whole grain samples of 1 g were placed in a 50-well, stainless steel plate and crushed using a hydraulic press to break seed coats and physically extrude oil. For oil extraction, 1 ml hexane was added to each sample of crushed seed. The reaction was covered with a glass plate to ensure the hexane did not evaporate and was left for 2 h to complete the reaction. A volume of 100 µl hexane and oil solution was removed from the crushing tray, mixed with 500 µl of 1 N sodium methoxide and transferred to a GC-FID autosampler vial. Vials were placed on a Labnet Vortex Mixer (Labnet International, Inc., Woodbridge, NJ) for 30-60 min until oil droplets were no longer floating in the sodium methoxide solution. After shaking, 1 ml of hexane and 150 µl of distilled water were added to each vial. Following inversion of the vial, the solution was allowed to sit for 20 min to complete the reaction. The addition of hexane and water results in the formation of two distinct layers within the solution. The upper, lower density layer of the solution containing FAME was removed and placed in another GC-FID autosampler vial while the lower layer was discarded. Samples were stored at 4°C until analysis.

Following the FAME reaction, samples were analyzed using GC-FID. A 6890 Agilent GC-FID equipped with a 30 m × 0.53 mm × 0.5 µm Supelco wax 10 capillary column (SUPELCO Inc., Bellefonte, PA) and HP 7673 autosampler (Agilent Technologies, Santa Clara, CA) were used to analyze FAME samples. Sample vials were loaded into the autosampler tray and a sample sequence was entered. GC-FID parameters included: an increase in oven temperature from 195°C to 240°C at 4°C/min and holding at 240°C for 2 min, injection volume of 1 µl with split ratio 20:1, inlet temperature of 220°C, and detector temperature of 290°C. Ultra high purity (99.999%) helium was used as carrier gas at a flow rate of 3.3 ml/min. Concentrations of the five major FAMEs were corrected with external standard (Supelco, Bellefonte, PA) calibration curves (0.05, 0.1, 0.2, 0.5, 1, 2, 5 mg/ml). Quadruplicate analyses were conducted for all samples.

Total Oil

Total oil content was determined using a protocol developed by Matthäus and Brühl (2001). An automated accelerated solvent extraction system ASE 200 (Dionex, Sunnyvale, CA) with 11 ml stainless steel sample cells was used for total oil extraction. Moisture content of ground oilseed samples was measured using a Moisture Analyzer A&D MF-50 (A&D Company Ltd, San Jose, CA). Three g of sample was transferred to an extraction cell, fitted with a cellulose filter, and fitted with a stainless steel frit at the outlet. The dead volume of the cell was filled with diatomaceous earth (Dionex, Sunnyvale, CA). The extraction cell was closed and automatically moved into the heatable extraction oven, filled with solvent, and pressure was adjusted. Following the extraction period, the extract was drained off into a collection vial which was purged with compressed nitrogen to determine oil composition. The extraction temperature was 105°C, with a preheat period of 6 minutes, and static extraction periods of 10 minutes with 2 cycles and a flush volume of 70% using hexane as a solvent were selected. Pressure was held at 1000 psi throughout the extraction. After processing, the extraction solvent hexane was evaporated by purging the samples with oxygen free compressed nitrogen gas. The residual hexane was evaporated in an oven at 105°C for approximately 60 min. The total oil content was calculated using AOCS Official Method AM 2-93 (AOCS, 2000):

$$\%C = 100 \times Qw / (W \times (1 - moisture\%))$$

in which *Qw* in grams is the total oil extracted, *W* in grams is the weight of the ground sample, and *moisture*% is the moisture percentage of the ground sample.

Total Crystalline Sugar

Total crystalline cellulose content was calculated as µg/mg cell wall material and analyses were performed in triplicate. Dried switchgrass samples were ground to a fine powder and pigments, proteins, lipids, and DNA were removed by washing the samples with organic solvents (York et al., 1985). The residue was de-starched with an amylase treatment resulting in only cell wall material remaining. The composition of the wall matrix polysaccharides was obtained by treating the samples with trifluoroacetic acid. Derivatization of the solubilized monosaccharides into their corresponding alditol-acetates and separation and quantification was conducted using gas chromatography employing a mass spectrometer (GC-MS) (Albersheim et al., 1967).

The remaining residue was washed with Updegraff reagent, an acid mix that results in stripping of further hemicelluloses and amorphous glucan (Updegraf, 1969). The remaining residue of crystalline cellulose was hydrolyzed with sulfuric acid (Seaman hydrolysis) (Selvendran and O'Neill, 1987) and the resulting monosaccharide quantified with a colorimetric assay (anthrone assay). Sugars extracted include rhamnose, arabinose, mannose, galactose, glucose, xylose, and arabinose. Levels of sugars are crop dependent and only whole plant switchgrass samples were analyzed for cellulosic ethanol potential. The matrix polysaccharide sugar composition gives indications about the presence and abundance of wall polymers. In the grasses, arabinose and xylose represent the hemicellulose arabinoxylan, mannose, the occurrence of glucomannan, and glucose represents the presence of amorphous cellulose.

Statistical Analysis

The experiments at all locations were established in a randomized complete block design (RCBD) with six replications at ROSE and four at MSU. Crop yield data analysis was conducted separately for each crop by year due to differing environmental conditions in 2007 and 2008. Gravimetric ethanol, total oil, FAME, and cellulose component yields were determined using a two year average to determine significance. Analysis of variance (ANOVA) was performed on crop yield and fuel quality and quantity using PROC MIXED in SAS (SAS Institute, 2009). The location treatments are considered fixed effects while blocks are considered a random effect. Results are based on the statistical model $y_{ij} = \mu + Location_i + Block_j + e$. Normality of residuals was assessed using PROC UNIVARIATE and Levene's test was used to test homogeneity of variances. When significant effects of treatment occurred, means were compared using Fisher's Protected Least Significant Difference (LSD). Unless otherwise stated, differences are considered significant at an alpha level of 0.05.

Economic Analysis

Enterprise budgets and machine and work rates estimates were based on Stein (2009). Seed prices were based on actual prices of purchased seed in 2007 and 2008. Fertilizer costs and herbicide prices were determined by Jorgensen Farms Elevator (Williamston, MI). Commodity prices were determined by National Agricultural Statistics Service for October 2008 (NAAS, USDA, 2008).

RESULTS AND DISCUSSION

Contaminant Analysis

Analysis of soil samples taken from ROSE in 2007 indicated PCB presence above a GC-ECD detection level of 0.28 ppm in each plot of block 4, regardless of bioenergy crop (Figure 2.1). A detection limit level of 0.28 ppm is a distinguishable PCB level discounting false-positives and discrepancies in GC instrumentation.

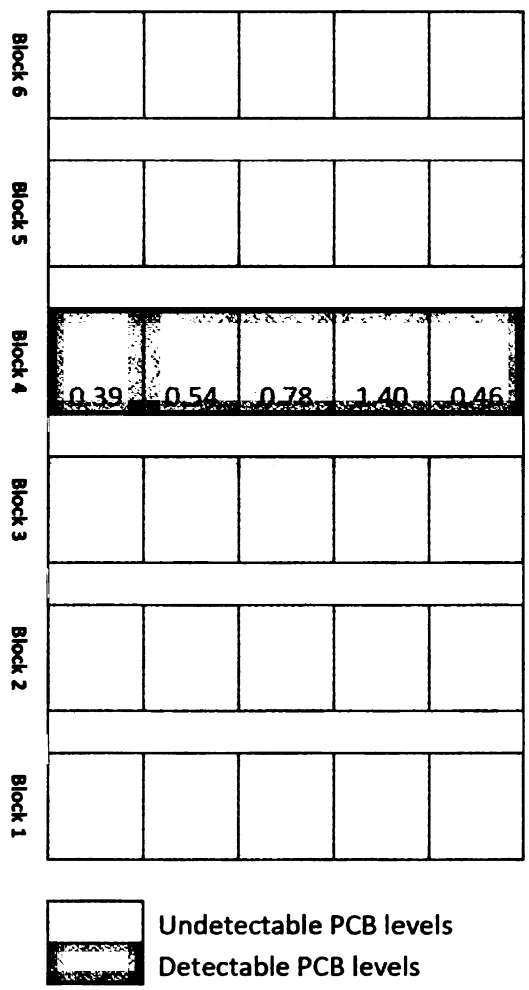

Figure 2.1. PCB soil sampling results from ROSE during 2007 (n=90).

PCB presence in block 4 may have been caused by improper capping procedures.

Pollutant analyses were also conducted on crop grain samples (n=24), with the exception of switchgrass, to determine potential plant uptake and translocation. No substance peaks or detection limits were identifiable on GC-ECD chromatograms including those for grain from block 4. Therefore, combustion of bio-based fuels produced from agronomic feedstock at ROSE would not adversely affect the environment.

<u>Environmental Conditions</u>

In 2007, precipitation at MSU was below average during the month of July (Table 2.5), and rain received late in the season slowed crop drying. In 2008, precipitation received during seedling establishment was below the 30-year average and rain received late in the season again slowed crop drying.

Table 2.5. Total monthly precipitation (cm) at MSU (East Lansing, MI) and ROSE (Rose Township, MI) in 2007-2008. Long term-means (1970-2000) included for comparison.

Location	Year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
MSU	2007	5.6	6.6	9.7	8.9	1.2	14.0	5.3	10.3
	2008	4.0	4.4	3.0	11.3	7.6	1.7	18.6	4.1
	30 yr.	5.7	7.5	7.5	9.3	7.9	7.8	6.3	5.5
ROSE	2007	8.0	5.7	6.3	5.3	3.5	16.6	3.5	6.5
	2008	5.3	2.6	5.5	13.1	6.2	3.2	20.0	3.4
	30 yr.	5.3	7.2	7.0	8.9	7.0	7.5	6.2	6.1

Precipitation at ROSE during the grain filling period of 2007 was below normal and rainfall during critical crop dry-down periods was above normal.

Droughty periods occurred during critical grain filling periods at both locations in 2007, negatively affecting yield. In 2008, precipitation was below the 30-year average during critical crop establishment periods, as well as in August, adversely affecting yield. Growing season precipitation was consistent with the 30-year average; however, the timing of rainfall events was irregular. Water availability, especially under marginal conditions, will be the primary management factor to determine productivity of bioenergy cropping systems (Stone et al., 2002; Jiang and Thelen, 2004). Crops with inherently high water use efficiency will achieve higher crop yields.

Due to the relative proximity of the experimental plots, average monthly air temperatures were similar. In 2007, average temperatures at MSU and ROSE tended to be slightly above 30-year means (Table 2.6).

Table 2.6. Average monthly air temperatures (°C) at MSU (East Lansing, MI) and ROSE (Rose Township, MI) in 2007-2008. Long-term means (1970-2000) included for comparison.

Location	Year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
MSU	2007	3.7	7.1	15.6	19.8	20.6	21.4	17.6	7.1
	2008	-0.2	9.9	12.6	19.6	21.5	20.7	17.4	9.7
	30 yr.	0.6	7.9	13.8	19.4	21.4	20.7	16.5	11.0
ROSE	2007	3.3	7.0	15.2	20.3	20.9	21.7	17.9	13.8
	2008	-0.4	9.7	12.4	19.9	21.3	20.4	17.3	8.9
	30 yr.	1.1	8.3	14.7	20.1	22.3	21.3	17.3	11.6

In 2008, temperatures at MSU were near the 30-year average while ROSE experienced a colder than normal year. However, 2008 data were almost identical at the two sites (Table 2.6).

Crop maturity can be predicted using daily average high temperatures and low temperatures to calculate Growing Degree Day units (GDD). GDD are calculated as the average of daily high and low temperatures less a base temperature of 10°C. In 2007, temperatures were warmer (Table 2.6) and more GDD were accumulated (Table 2.7) than in 2008, at both sites.

Table 2.7. Monthly and yearly accumulation of Growing Degree Day units at MSU (East Lansing, MI) and ROSE (Rose Township, MI) during 2007 and 2008, calculated using a base temperature of 10°C.

		Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Total GDD
MSU	2007	26.4	38.4	176.4	295.6	326.4	354.1	230.2	140.4	1587.9
	2008	0.1	68.9	85.8	286.9	356.8	330.0	222.8	53.2	1404.6
ROSE	2007	21.3	37.7	163.2	309.9	337.1	362.9	238.9	142.3	1613.3
	2008	0.0	64.4	78.4	296.4	352.2	321.3	217.9	38.0	1368.7

In 2007, ROSE accumulated 1613 GDD while MSU had 1588 GDD, a 2% difference. Conversely, in 2008, MSU accumulated more GDD than ROSE, a 3% difference. Summed GDD over both years indicated similar conditions at MSU and ROSE, with less than 1% difference between the two locations. Locations which receive more GDD have the potential to achieve higher yield totals (Swanson and Wilhelm, 1996). Given that GDD accumulations were similar at the two locations, temperature had little effect on yield differences.

Agronomic Yield

Differences between sites included climate, soil type, shading, crop demands, and logistics requiring differing harvest dates (Table 2.4). Canola, on average, contains 40% oil, making the seed a very attractive food and energy source for birds, in particular the American Goldfinch (*Carduelis tristis* L.). In 2008, swathing canola before it reached physiological maturity resulted in 5% higher yields (S. Smith and K. Thelen, unpublished data). Canola was swathed when 60-75% of the seeds were black and contained 30-40% moisture as recommended by Oklahoma State University Extension (2007). To protect sunflower crop yield in both years, plots were hand harvested and dried when they had reached fully physiological maturity (R9) but had not yet dried to acceptable mechanical harvest moisture percentages or storage moistures of 9.5%.

Statistical analysis determined that blocking within locations was not a significant factor ($p > 0.05$). Therefore, crop yield totals from all plots per crop were averaged to determine a yield mean for each location. MSU and ROSE yield means differed ($p < 0.05$) in both years (Table 2.8).

Table 2.8. Mean crop yields of bioenergy crops in 2007 and 2008 at MSU (n=4) and ROSE (n=6). Means within a year and crop followed by a common letter are not different at ($p < 0.05$) using Fisher's Protected Least Significant Difference test.

Crop	Yield (Mg ha^{-1})			
	2007		2008	
	MSU	ROSE	MSU	ROSE
Corn	4.87 a	3.91 a	9.89	‡
Soybean	1.83 a	2.40 a	2.10 b	2.56 a
Sunflower	2.54 a	1.16 b	2.70 a	2.66 a
Canola	†	†	0.04 b	0.41 a
Switchgrass	0.61 b	4.14 a	7.39 a	7.46 a

†Yield data not computed due to wildlife damage; samples retained for quality analysis.

‡Yield data not computed due to wildlife damage.

In 2007, grain yield of corn and soybean did not differ between locations. Sunflower yields at ROSE were lower at 1.16 compared to 2.54 Mg ha^{-1} at MSU. Conversely, biomass yield of switchgrass was higher at 4.14 Mg ha^{-1} at ROSE compared to 0.61 Mg ha^{-1} at MSU. Yield comparisons of canola could not be made due to wildlife damage. In 2008, canola and soybean yields at ROSE were 0.41 and 2.56, respectively, compared to 0.04 and 2.10 Mg ha^{-1} at MSU, while sunflower and switchgrass yields were not statistically different. Comparisons of 2008 corn yield could not be made as plots were not harvested at ROSE due to wildlife damage.

Crop establishment as well as favorable environmental conditions, are vital for optimum crop yield. In 2008, crop yields at both locations were higher than 2007 as crop management practices were refined the second year of the study. In particular, switchgrass biomass yields were low in 2007 partly due to whole-plot harvests while quadrants harvests were used in 2008. Additionally, switchgrass physiology dictates higher yield as a switchgrass stand matures as 2008 switchgrass yields were consistent with that of other marginal locations as found by Schmer et al. (2008). Weed species including spotted knapweed (*Centaurea maculosa* Lam.) and common lambsquarters (*Chenopodium album* L.) slowed early crop growth and competed with crops as determined by low sunflower yields. All together, these factors were likely more influential in determining yields than the differences in soil fertility levels between the two sites.

Corn Grain Ethanol Yield

Gravimetric fermentation of corn grain is standard industry practice for ethanol production. In 2007, there was no difference in ethanol yield from MSU and ROSE following fermentation (Figure 2.2). Ethanol yields at MSU and ROSE of 0.4530 and 0.4532 L ethanol / kg corn were consistent with industry average yields of 0.4173 L/kg (Bothast and Schlicher, 2004).

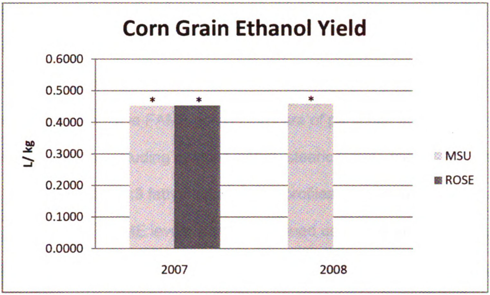

Figure 2.2. Corn grain ethanol yields for 2007 (MSU and ROSE) and 2008 (MSU); * represents no statistical significance at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

Comparable ethanol yields were likely due to equal latitude and similar GDD of the two sites. In 2008, corn grain from MSU yielded 0.4595 L/kg, which was only a 1.4% L/kg increase from 2007.

Factors that influence the ethanol yield potential of corn grain are difficult to use as yield predictors because they are not well understood. Dein et al. (2002) found that the starch content of corn did not correlate well with ethanol yields. They suggested that ethanol yield may be affected by climatic conditions and locations. The present research indicates that, similar to grain yield, ethanol yield was not affected by the relatively low soil fertility at the ROSE brownfield site.

Fatty Acid Methyl Esters Yield

Biodiesel, which consists of fatty acid methyl esters (FAME), is derived from triglycerides through a process termed transesterification. Following triglyceride extraction, five FAME compounds are of particular interest for biodiesel production, including palmitic C16:0, stearic C18:0, oleic C18:1, linoleic C18:2, and linolenic C18:3 fatty acids. FAME profiles will vary among crops and growing conditions. FAME levels were determined using gas chromatography with a flame ionization detector (CG-FID), with combined two-year results indicating minimal significant differences between MSU and ROSE (Table 2.9).

Table 2.9. Results of fatty acid methyl ester (FAME) analysis of oilseed crops at MSU and ROSE, 2007 and 2008 dates combined (mean percent of total oil content by weight); % FAME followed by a differing letter within a fatty acid are significant at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

		% fatty acid methyl esters/ml crop oil									
	n	**Palmitic**		**Stearic**		**Oleic**		**Linoleic**		**Linolenic**	
Soybean											
MSU	32	11.68	a	5.33	a	24.63	a	50.92	b	7.44	b
ROSE	48	10.29	b	4.89	b	24.96	a	51.61	a	8.25	a
Canola											
MSU	32	5.11	a	2.27	a	60.65	a	22.60	a	9.37	a
ROSE	48	4.78	a	1.96	b	60.21	a	23.31	a	9.74	a
Sunflower											
MSU	32	5.18	a	4.74	a	77.36	a	12.63	a	†	
ROSE	48	5.02	a	5.37	a	78.04	a	11.48	a	†	

† Sunflower oil does not contain linolenic FAME.

In soybean, the palmitic, stearic, linoleic, and linolenic FAME percentages differed significantly between MSU and ROSE and data were consistent with those determined by Goering et al. (1982). Palmitic acid is the most common saturated fatty acid found in plants (Goering et al.,1982; Kincs, 1985). Because they are highly saturated, palmitic and stearic acids have high viscosity, causing gelling and coagulation problems in diesel engines (Pryde, 1983; Ma and Hanna, 1999); therefore, low levels of palmitic and stearic acid are desirable. Linoleic and linolenic FAME are unsaturated omega-6 fatty acids. Biodiesel with high levels of linoleic and linolenic fatty acids, due to their unsaturation, has reduced storage duration. Given these factors, optimum biodiesel is obtained by optimizing oleic fatty acid levels. In soybean, canola, and sunflower, oleic acid levels were not significantly different between MSU and ROSE, suggesting similar fuel quality. Stearic fatty acid levels in canola were lower at ROSE than at MSU. In sunflower, no differences in levels of all FAME tested were found (Table 2.9).

Izquierdo et al. (2002) found that the oleic: linoleic ratio depends on the temperature during the early stages of oil synthesis in oilseeds. Due to close proximity and latitude of the two research locations, no temperature differences (Table 2.6) were experienced, resulting in no differences in FAME levels (Table 2.9). Thus, brownfield acreage can be expected to provide adequate oilseed quality and can be used to increase the oilseed supply available for conversion to biodiesel fuels.

Total Oil Yield

Two-year average total oil content for the oilseed crops did not differ between MSU (n=8) and ROSE (n=12) (Figure 2.3). Total oil yield did not appear to be affected by soil fertility levels.

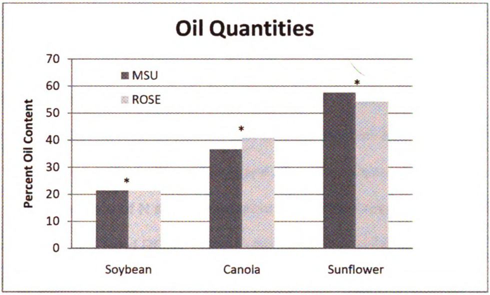

Figure 2.3. Mean total oil content (% by weight) of soybean, canola, and sunflower of oilseed crops at MSU and ROSE, 2007 and 2008 dates combined; * represents no significance at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

The range of soybean total oil content was 21.4 to 21.5% of seed dry mass, which is consistent with data reported by Dardanelli et al. (2006).

Sunflower seed accumulates oil in the final stage of reproductive growth, and oil content can differ with environmental conditions including soil type, shading, agronomic practices, and precipitation (Zheljazkov et al. 2008). Seed oil concentration is important for growers and processors. For example, sunflower crushing plants in North Dakota and Kansas offer a 2% price premium for every 1% oil above 40% (National Sunflower Association 2007). No location differences were observed with sunflower at MSU yielding 57.6 and ROSE yielding 54.3% oil. However, these percentages may be slight overestimates because a small fraction of seed coats could not be removed from the samples and was included in the oil extraction process.

Jackson (2000) found that seed oil content of canola was reduced by increasing applications of N fertilizer. At both MSU and ROSE, canola was treated with the same, low-input fertilizer regime with no additional N amendments. Canola total oil content can also be reduced by low levels of precipitation during critical oilseed filling and oil accumulation periods (Chen et al. 2005). In the absence of N supplementation and water stress, canola oil content at both MSU (36.7%) and ROSE (40.9%) fell within the range reported by Sosulskl et al. (1988). Again, the brownfield site produced oilseed crops including canola, soybean, and sunflower of equal oil content as the conventional agronomic site (Figure 2.3).

Total Crystalline Cellulose Yield

In 2007, average crystalline cellulose content of switchgrass was higher at MSU than at ROSE (Figure 2.4). In 2008, no difference between locations of switchgrass crystalline cellulose content was detected.

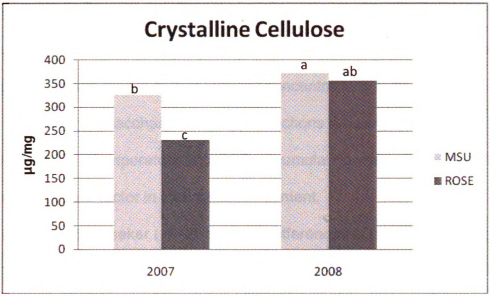

Figure 2.4. Average crystalline cellulose content of switchgrass at MSU and ROSE, in µg cellulose/mg switchgrass. Location means followed by a differing letters are significant at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

Switchgrass grown at MSU yielded higher levels of crystalline cellulose as compared to ROSE in 2007 but not 2008. Stand maturity may influence increased cellulose content (Gomide et al., 1969). MSU switchgrass yielded 12% less cellulose in 2007 than in 2008. In 2008, stands yielded equal biomass and crystalline cellulose levels at MSU and ROSE. In 2007, second-year stands at MSU and ROSE produced significantly lower crystalline cellulose content as compared with three-year stands in 2008. ROSE produced significantly less cellulose than MSU in 2007. Levels of crystalline cellulose of weed species, though not quantified, could have decreased levels at ROSE.

Switchgrass is a photoperiod-sensitive plant. Switchgrass cellulose concentration and composition can be influenced by many environmental factors (Moser and Vogel 1995). Temperature is the environmental factor that most strongly affects plant cell walls, with high temperatures causing increased rate of reproductive maturation. Temperature and water stress can affect morphological development by resulting in higher cell wall concentrations, with increases occurring in both polysaccharide and lignin fractions reducing total sugar (Buxton and Fales, 1994). Temperature and GDD accumulation were similar at both sites and was not likely a factor in total cellulose content.

Patton and Gieseker (1942) reported differences in cellulose and lignin content depending upon maturity as well as grass species. Switchgrass grown in 2007 at MSU contained 29% more crystalline cellulose than that grown at ROSE, while 2008 results were not significant. Differences between locations can, in part, be attributed to percent stand. Pure switchgrass samples could not be collected from ROSE in 2007 due to inconsistent stands. Over two years and two different sampling practices, similarities in total cellulose at ROSE were present when pure switchgrass samples were collected due to similar fertility base stand issues.

Economic Analysis

Producers planning to implement bioenergy cropping rotations in their farming operations will make decisions based ultimately on optimizing economic returns. Under marginal land conditions, positive economic outcomes will be possible if the input costs are limited.

Table 2.10. Economic return utilizing marginal land (ROSE) compared to traditional cropping system (MSU) acreage.

Crop	Economic Outcomes			
	2007		2008	
	MSU	ROSE	MSU	ROSE
Corn	-	+	+	X
Soybean	-	+	+	+
Sunflower	+	+	+	+
Canola	X	-	X	-
Switchgrass	-	-	+	+

- Represents an economic net loss
+ Represents an economic net gain
X Indicates the crop was not harvested

In 2007, estimated economic returns were positive only for sunflower at MSU while corn, soybean, and sunflower returned economic gains at ROSE. However at MSU, returns from corn, soybean, and sunflower in 2008 all provided a financial advantage. In both years and sites, canola yields were reduced by wildlife damage. Although, switchgrass does not currently have market value as a bioenergy crop, however \$41.50 Mg^{-1} (dry weight basis) price projections were adapted from Sokhansanj et al. (2009). Production and economic analysis of a perennial crop lends to different inputs depending on maturity of the stand. Results of switchgrass economics indicate a profit following the establishment year. Agronomic and management practices need to be refined for all bioenergy crops to be profitable under marginal conditions. Under ideal field conditions, all crops have the potential to be profitable. More years of research are needed to determine modeling for economic analysis.

Determining the optimum bioenergy crop to be grown for profit on remediated brownfield sites cannot be easily determined. Currently, cellulosic ethanol is not commercially produced on a large scale in the U.S. McLuughlin and Kszos (2005) have reported that the economic return of ethanol production from lignocellulosic sources surpasses that of annual crops. Under current industry practices, and given environmental conditions at ROSE during 2007 and 2008, the greatest economic return was obtained from corn and sunflower. Once cellulosic production technologies are refined, switchgrass production on marginal sites may prove to return the highest economic gains.

CONCLUSIONS

The ROSE brownfield site provided bioenergy crop yield and quality similar to that from noncontaminated agricultural land, suggesting the potential for similar brownfield sites across the Midwest to also be viable options for bioenergy production. Soil analysis indicated PCB levels in block 4 at ROSE; however, no traces of contaminant were found in the feedstock. Fuel quantity and quality including ethanol, total oil, crystalline cellulose, and FAME produced from marginal brownfield sites showed minimal differences when compared to areas with traditionally high fertility. Preliminary economic analysis supports potential investment in economic endeavors on brownfield acreage. Perennial cellulosic crops such as switchgrass hold great promise for production on brownfield sites where water availability and soil fertility will limit yield of annual crops. Increasing available feedstock for energy production on alternative production sites eases the stress on market demand for food crops. However, brownfield sites should be approached on a case-by-case basis as some pollutants may still prove to be a detriment to the environment following fuel conversion and combustion. Sustainability of long-term cropping systems on brownfield sites is vital and must be further explored; for example, soil fertility degradation of marginal lands under long-term crop production needs further research in efforts to model fertility trends.

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APPENDICES

Appendix 2.1. Economic analysis of MSU in 2007 utilizing actual yields.

	$ ha $^{-1}$				
MSU 2007	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	169	968	581	4623	28
CASH EXPENSES					
Seed	71	287	83	37	92
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	6
Energy	316	386	319	386	782
Machinery and Repairs	217	219	178	213	536
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	1459
REVENUE ABOVE CASH EXPENSES	-522	-48	-73	3836	-1431

Appendix 2.2. Economic analysis of ROSE in 2007 utilizing actual yields.

	$ ha $^{-1}$				
ROSE 2007	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	64	1179	866	2118	110
CASH EXPENSES					
Seed	71	287	83	37	92
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	6
Energy	316	386	319	386	782
Machinery and Repairs	217	219	178	213	536
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	1459
REVENUE ABOVE CASH EXPENSES	-627	163	212	1331	-1349

Appendix 2.3. Economic analysis of MSU in 2008 utilizing actual yields.

	$\$ ha^{-1}$				
MSU 2008	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	23	1548	676	1380	338
CASH EXPENSES					
Seed	71	287	83	37	0
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	9
Energy	316	386	319	386	36
Machinery and Repairs	217	219	178	213	140
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	229
REVENUE ABOVE CASH EXPENSES	-668	532	22	593	109

Appendix 2.4. Economic analysis of ROSE in 2008 utilizing actual yields.

ROSE 2008	Canola	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	169	833	2403	341
CASH EXPENSES				
Seed	71	83	37	0
Fertilizer	19	19	70	19
Herbicides	43	30	56	9
Energy	316	319	386	36
Machinery and Repairs	217	178	213	140
Labor	25	25	25	25
TOTAL CASH EXPENSES	691	654	787	229
REVENUE ABOVE CASH EXPENSES	-522	179	1616	112

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Chapter 3. Use of Agronomically Marginal Land for BioEnergy Production

ABSTRACT

Agriculture faces unique challenges as increasing world population places unprecedented demands on food, feed, and energy resources. Agricultural resources are becoming increasingly stretched to meet the demands of both food and fuel production. Marginal land could be utilized for bioenergy crop production. In 2007 and 2008, we evaluated corn (*Zea mays* L. ssp. *mays*), soybean (*Glycine Max* (L.) Merr.), canola (*Brassica napus* L. var. *napus*), sunflower (*Helianthus annuus* L.), and switchgrass (*Panicum virgatum* L.) at three sites to determine the highest-yielding crop for bioenergy production. Sites selected for the study included two marginal sites, one at Lake City (LC), Missaukee County, 44° 18'N, 85° 12'W (LC), the other at Chatham (UP), Alger County, 46° 20'N, 86° 54'W, for comparison with a historically cropped site at East Lansing (MSU), Ingham County, 42° 41'N, 89° 29'W. Comparisons of biofuel crop quality components were also conducted. Yield of all crops differed among locations; however, the historically cropped site did not consistently provide higher yields than LC and UP. Ethanol produced from corn grain (L/kg) differed significantly ($p<0.05$) between locations: as latitude increased, ethanol yield decreased. Total oil content of soybean was reduced with increases in latitude, while the reverse was true of canola. Concentrations of palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) fatty acids showed that northern locations yielded higher levels of oleic acid for soybean and canola, while no differences were detected in sunflower. Total crystalline cellulose levels from switchgrass were highest at MSU in 2008; however, the

MSU stand was one year older. Stands equal in age, regardless of location, were not significantly different in cellulose content.

INTRODUCTION

Energy production from agricultural crops in the United States has become an ethical dilemma (Caims, 2007). Crops once reserved for food, feed, and fiber are now allotted to energy production, potentially reducing the amount of commodities available for human consumption. Expanding bioenergy crop production acreage into areas not currently cultivated for agronomic yield could offset the demand for consumption crops designated for energy production (Walsh et al., 2003). One way to diminish this competition is to produce bioenergy feedstock in areas not currently being used for production agriculture.

Marginal land is commonly seen as unsuitable for cultivation of arable crops and can be classified using various factors. The United States Department of Agriculture has eight land capability classes based on level of agricultural suitability. Classes III and IV are capable of producing crops yet have severe use limitations, which include features such as slope, erosion, flooding, low moisture holding capacity and fertility, salinity, and adverse climatic conditions (Natural Resources Conservation Service, 2009).

In the contiguous 48 states of the U.S., 174.6 million hectares are identified as cropland (USDA, NAAS, 1999). The Conservation Reserve Program (CRP), which grants government payment for protection of sensitive lands with capability classes of III and IV primarily, compensates owners for 12.1 million hectares nationwide (USDA FSA, 1999). According to Walsh et al.

(2003), 6.8 million hectares of the 12.1 million hectares of CRP could be used to grow bioenergy crops in addition to 7.7 million hectares classified as idle. Continuous moisture stress, the most limiting factor of crop yield, affects 3.7 billion hectares in the U.S. which contribute to 27.9% of the total available landbase. Low temperatures and short growing seasons in northern climates limit yield and occur on 2.2 billion hectares of the earth's potential landbase (USDA-ERS, 2003). Utilizing lands where marginal conditions limit production could supplement the growing needs for renewable fuels.

Switchgrass has been studied to determine if this perennial grass is competitive under marginal conditions (Mooney et al., 2005). Additionally, comparisons between corn grain and stover yield and switchgrass biomass have been explored in marginal environments (Varvel et al., 2008). However, little information is available on multi-crop comparisons between corn (*Zea mays* ssp. *mays*), soybean (*Glycine Max* (L.) Merr.), canola (*Brassica napus* L. var. *napus*), sunflower (*Helianthus annuus*), and switchgrass (*Panicum virgatum* L.) production on marginal soils. It is currently unknown whether marginal land can produce adequate yield to offset capital investments, or whether crops grown on various types of marginal land will yield biofuel of adequate quality.

U.S. food and energy independence could be attained by efficient land use strategies for bioenergy production, including cultivation of idle marginal land, if fuel quality standards are met. In this study we sought to 1) evaluate bioenergy crop yield on two marginal sites; 2) identify the optimal bioenergy crop for each location; and 3) compare the quality of fuel derived from marginal sites to that of fuel derived from traditional cropping systems.

MATERIALS AND METHODS

Site Description

Field experiments were conducted in 2006-2008 at marginal field sites in Chatham (UP), at the MSU Upper Peninsula Experiment Station, Alger County, and in Lake City (LC), at the Lake City Experiment Station, Missaukee County in 2007. A third site of high fertility agricultural land was established in East Lansing (MSU), at the Michigan State University Agronomy Research Farm, Ingham County in 2006 to serve as an experimental control for crop yield and quality analyses. Crops evaluated included corn, soybean, canola, sunflower, and switchgrass; sunflower was omitted at UP. Site characteristics are listed in table 3.1.

Table 3.1. Site characteristics of location, elevation, soil type, land capability class, pH, P and K levels.

Site	Location	Elevation m	Soil Type	Land Capability Class	pH	P	K
						meq	
MSU	42° 41'N 89° 29'W	261	Capac Loam (fine-loamy, mixed, mesic, Aeric Ochraqualfs)	II	6.0	3.3	8.1
LC	44° 18'N 85° 12'W	377	Montcalm-Graycalm complex (coarse-loamy, mixed, frigid Eutric Glossoboralfs and Alfic Upidsamments	III	5.6	6.0	1.1
UP	46° 20'N 86° 54'W	368	Eben very cobbly sandy loam (sandy-skeletal, mixed frigid Pachic Hapludolls)	VI	7.5	3.1	7.6

Site history at LC included a previous crop of alfalfa in 2006 while UP was planted to corn grown for silage. In 2005 at MSU, the previous crop was soybean.

Cultural and Management Practices

Tillage methods took into account site-specific soil characteristics and local production practices. At MSU and LC, plot preparation included spring chisel plowing prior to planting. UP site preparation was minimal as crops were no-tilled planted in 2007 and 2008. Soil features including location, elevation, soil type, land capability class, pH, and soil fertility levels for all locations are shown in Table 3.1.

Seeding dates, rates, and varieties are shown in Table 3.2. Varieties were selected according to Michigan maturity zones.

Table 3.2. Planting date, seeding rate, and seed selection for MSU, LC, and UP.

Crop	Location	Date		Rate	Variety
		2007	2008	ha $^{-1}$	
Corn	MSU	May 21	May 13	74,131†	Dekalb 38H66-RR2
	LC	May 21	May 13	74,131†	Dekalb 38H66-RR2
	UP	May 20	May 14	74,131†	Dekalb DKC 33-11
Soybean	MSU	May 21	May 13	444,785†	Diehl Fields DF8242RR
	LC	May 21	May 13	444,785†	Diehl Fields DF8242RR
	UP	June 06	June 04	555,986†	Wolf River Valley WRV 2905
Canola	MSU	May 21	April 30	6.72‡	Dekalb DKL 38-25RR
	LC	May 21	April 30	6.72‡	Dekalb DKL 38-25RR
	UP	May 11	May 08	8.40‡	Dekalb DKL34-55
Sunflower	MSU	May 21	May 13	74,131†	Seeds 2000 Charger
	LC	May 21	May 13	74,131†	Seeds 2000 Charger
	UP	-	-	-	-
Switchgrass	MSU	May 21*	-	11.2#	Forage First Forestburg
	LC	May 21	-	11.2#	Forage First Forestburg
	UP	June 27	-	11.2#	Ernst Conservation Seeds Cave in Rock

*Reseeded switchgrass stand

† Seeding rate in seeds ha^{-1}

‡Seeding rate in kg ha^{-1}

Seeding rate in kg pure live seed ha^{-1}

Planting of annual crops at MSU and LC followed a canola-corn-soybean-sunflower rotation with switchgrass remaining in dedicated plots. Switchgrass was initially planted in 2006 and was no-till replanted at MSU in 2007 due to low populations. At UP, planting of annual crops followed a canola-corn-soybean rotation with switchgrass remaining in dedicated plots.

At MSU and LC in 2007, corn, soybean, and sunflower were planted with a custom built planter utilizing John Deere row and vacuum units (Deere & Company, Moline, IL), while canola and switchgrass were planted with an

Almaco drill (Almaco, Nevada, IA). In 2008, corn, soybean, and sunflower were planted with a custom planter utilizing John Deere row units equipped with MaterMacc (MaterMacc, San Vito al Tagliamento, Italy) metering units, while canola was planted with an Almaco drill. At UP in 2007 and 2008, a John Deere 7000 no-till vacuum planter was used to plant corn and a Lilliston no-till seed drill (Agco, Duluth, GA) was used to plant canola, soybean and switchgrass.

Herbicide labels were followed for application rates and timing was crop-dependent as shown in Table 3.3.

Table 3.3. Postemergence herbicide applications and timing.

Crop	Location	Glyphosate	Glufosinate	Atrazine	Acetochlor	Quinclorac
				Date (2007, 2008)		
Corn	MSU	5/23, 5/ 15				
	LC	5/23, 5/15				
	UP			5/31, 5/22	5/31, 5/22	
Soybean	MSU	5/23, 5/15				
	LC	5/23, 5/15				
	UP	7/9, 6/27				
Canola	MSU	5/23, 5/15				
	LC	5/23, 5/15				
	UP	6/9, 6/9				
Sunflower	MSU		5/24, 5/24			
	LC		5/24, 5/24			
Switchgrass	MSU			5/12, 5/10		*, 5/10
	LC			5/12, 5/10		
	UP					*, 6/4

* No application was made in 2007

Nitrogen soil amendments were side-dressed at rates of 112 kg ha^{-1} in corn and sunflower. Other crops received no fertilization.

Harvest and Handling

In 2006, crops at MSU were planted and harvested to establish the rotational system, but yield totals were not recorded. LC and UP crops were established in 2007. Harvest dates for 2007 and 2008 are presented in Table 3.4.

Table 3.4. Harvest dates at MSU, LC, and UP.

Crop	Harvest Date					
	MSU		LC		UP	
	2007	2008	2007	2008	2007	2008
Corn	Oct. 12	Oct. 29	Oct. 21	Oct. 29	Oct. 25	Nov. 3
Soybean	Oct. 11	Oct. 22	Oct. 11	Oct. 23	Oct. 30	Oct. 31
Sunflower	Sept. 10	Sept. 17	Sept. 11	Sept. 20	-	-
Canola	†	July 22	Aug. 22	July 24	Aug. 23	Aug. 11
Switchgrass	Nov. 1	Oct. 29	Oct. 30	Oct. 29	‡	Oct. 31

†Crop not harvested due to wildlife damage.

‡Crop not harvested.

In 2007 at MSU and LC, corn and soybean grain yields were determined by whole- plot harvests using a small plot combine (Massey Ferguson 8XP, AGCO, Batavia, IL), and by flail harvester (Carter Manufacturing Co. Inc., Brookston, IN) for switchgrass. Two sunflower and canola rows, 1 m in length with three replicates per plot, were harvested by hand. At UP, corn, soybean, and canola were whole-plot harvested using a small-plot combine (Massey Ferguson 8XP, AGCO, Batavia, IL). Likewise, canola was whole-plot harvested using a small-plot combine (Almaco, Nevada, IA). In 2008, only subplot areas not affected by wildlife damage were harvested. In corn, 1.5 by 12.9 m was hand-harvested from two areas of each plot. In soybean 1.1 by 12.9 m was hand-harvested from three areas of each plot. In canola, three areas 1.5 by 12.2 m were swathed (Swift Machine, Swift Current, SK), then threshed (Almaco, Nevada, IA). In sunflower, three areas 1.5 by 1 m were hand-harvested and sunflower heads were threshed (Almaco, Nevada, IA). In switchgrass, three 50.8 by 50.8 cm quadrats were hand-harvested at a cutting height of 7.6 cm from the soil surface. At UP, whole-plot harvests were used for corn, soybean, and canola. In switchgrass, three 50.8 by 50.8 cm quadrats were hand-harvested at a cutting height of 7.6 cm from the soil surface. To eliminate potential bias associated with wheel tracks and implement overlap, only the center rows of each planter pass were harvested.

Grain moisture levels were determined using a DICKEY-john GAC 2100 grain analysis computer (DICKEY-john, Auburn, IL). Grain samples were oven-dried at 60°C to 15.5, 13.0, 8.5, and 10.0% storage moisture for corn, soybean, canola, and sunflower, respectively. Switchgrass samples were weighed in the field, oven dried at 100°C for 4 days, and weighed again to determine dry matter content.

At UP, switchgrass stands in 2007 did not have enough carbohydrate reserves for cutting. Additionally, above-ground biomass was not substantial and was left standing throughout the winter. Sunflower was not planted at UP as the site's climatic features and latitude are not conducive to sunflower production.

Corn Grain Ethanol

Triplicates of 25 g ground corn grain samples were used for ethanol analysis following a gravimetric, 72 h fermentation method described by Lemuz et al. (2004). Each 25 g ground corn sample was mixed with 75 ml deionized water and 27 µl alpha-amylase (9000-85-5, Sigma-Aldrich Inc., Allentown, PA) to break the α1-6 linkage in the starch and form single glucose molecules in an Erlenmeyer flask fitted with a rubber cap and needle vent. The slurry was incubated in a 90°C oven for 90 min with occasional shaking. The slurry temperature was then lowered to 60°C, and the pH was adjusted to 4.1-4.5 with hydrochloric acid (EMD Chemicals Inc. Gibbstown, NJ). The liquefied corn slurry was saccharified and fermented simultaneously by adding 20 µl glucoamylase (9032-08-0, Sigma-Aldrich Inc.), 5 ml yeast inoculum and 0.4 ml 1M NH_4SO_4 (EM Science, Gibbstown, NJ). The flask was placed in a 60°C oven for 2 h before it was placed in an incubator shaker at 32°C at 150 rpm for 72 h (Model C25, New Brunswick Scientific, Edison, NJ). The yeast inoculum was prepared according to Wang et al. (1999). Briefly, active dry yeast (Fleischmann's yeast, Fenton, MO) was dispersed in 99 ml of 0.1% sterile peptone water (DOT Scientific Inc. Burton, MI) and prewarmed at 38°C. The flask with the slurry was weighed together before and after the incubation, and the difference in weight was considered as the mass of CO_2 released during the fermentation. Assuming 100% recovery, total ethanol produced was computed using a 1:1 molar ratio of ethanol to CO_2 and the following conversion:

$$n = ((W1-W2)/44) \times 46$$

where n is the total ethanol yield in grams, W1 in grams is the weight of the solution before fermentation, W2 in grams is the weight of the solution following fermentation, 44 is the molecular weight of CO_2, and 46 is the molecular weight of ethanol.

Fatty Acid Methyl Esters

Fatty acid methyl ester (FAME) quantities in oil seed crops were using a protocol adopted from Hammond (1991). Subsamples of soybean, canola, and sunflower seed were collected at the time of harvest. Whole grain samples of 1 g were placed in a 50-well, stainless steel plate and crushed using a hydraulic press to break seed coats and physically extrude oil. For oil extraction, 1 ml hexane was added to each sample of crushed seed. The reaction was covered with a glass plate to ensure the hexane did not evaporate and was left for 2 h to complete the reaction. A volume of 100 µl hexane and oil solution was removed from the crushing tray, mixed with 500 µl of 1 N sodium methoxide and transferred to a GC-FID autosampler vial. Vials were placed on a Labnet Vortex Mixer (Labnet International, Inc., Woodbridge, NJ) for 30-60 min until oil droplets were no longer floating in the sodium methoxide solution. After shaking, 1 ml of hexane and 150 µl of distilled water were added to each vial. Following inversion of the vial, the solution was allowed to sit for 20 min to complete the reaction. The addition of hexane and water results in the formation of two distinct layers within the solution. The upper, lower density layer of the solution containing FAME was removed and placed in another GC-FID autosampler vial while the lower layer was discarded. Samples were stored at 4°C until analysis.

Following the FAME reaction, samples were analyzed using GC-FID. A 6890 Agilent GC-FID equipped with a 30 m × 0.53 mm × 0.5 µm Supelcowax 10 capillary column (SUPELCO Inc., Bellefonte, PA) and HP 7673 autosampler (Agilent Technologies, Santa Clara, CA) were used to analyze FAME samples. Sample vials were loaded into the autosampler tray and a sample sequence was entered. GC-FID parameters included: an increase in oven temperature from 195°C to 240°C at 4°C/min and holding at 240°C for 2 min, injection volume of 1 µl with split ratio 20:1, inlet temperature of 220°C, and detector temperature of 290°C. Ultra high purity (99.999%) helium was used as carrier gas at a flow rate of 3.3 ml/min. Concentrations of the five major FAMEs were corrected with external standard (Supelco, Bellefonte, PA) calibration curves (0.05, 0.1, 0.2, 0.5, 1, 2, 5 mg/ml). Quadruplicate analyses were conducted for all samples.

Total Oil

Total oil content was determined using a protocol developed by Matthäus and Brühl (2001). An automated accelerated solvent extraction system ASE 200 (Dionex, Sunnyvale, CA) with 11 ml stainless steel sample cells was used for total oil extraction. Moisture content of ground oilseed samples was measured using a Moisture Analyzer A&D MF-50 (A&D Company Ltd, San Jose, CA). Three g of sample was transferred to an extraction cell, fitted with a cellulose filter, and fitted with a stainless steel frit at the outlet. The dead volume of the cell was filled with diatomaceous earth (Dionex, Sunnyvale, CA). The extraction cell was closed and automatically moved into the heatable extraction oven, filled with solvent, and pressure was adjusted. Following the extraction period, the extract was drained off into a collection vial which was purged with compressed nitrogen to determine oil composition. The extraction temperature was 105°C, with a preheat period of 6 minutes, and static extraction periods of 10 minutes with 2 cycles and a flush volume of 70% using hexane as a solvent were selected. Pressure was held at 1000 psi throughout the extraction. After processing, the extraction solvent hexane was evaporated by purging the samples with oxygen free compressed nitrogen gas. The residual hexane was evaporated in an oven at 105°C for approximately 60 min. The total oil content was calculated using AOCS Official Method AM 2-93 (AOCS, 2000):

$$\%C = 100 \times Qw / (W \times (1\text{-} \mathit{moisture}\%))$$

in which *Qw* in grams is the total oil extracted, *W* in grams is the weight of the ground sample, and *moisture*% is the moisture percentage of the ground sample.

<u>Total Crystalline Sugar</u>

Total crystalline cellulose content was calculated as µg/mg cell wall material and analyses were performed in triplicate. Dried switchgrass samples were ground to a fine powder and pigments, proteins, lipids, and DNA were removed by washing the samples with organic solvents (York et al., 1985). The residue was de-starched with an amylase treatment resulting in only cell wall material remaining. The composition of the wall matrix polysaccharides was obtained by treating the samples with trifluoroacetic acid. Derivatization of the solubilized monosaccharides into their corresponding alditol-acetates and separation and quantification was conducted using gas chromatography employing a mass spectrometer (GC-MS) (Albersheim et al., 1967).

The remaining residue was washed with Updegraff reagent, an acid mix that results in stripping of further hemicelluloses and amorphous glucan (Updegraf, 1969). The remaining residue of crystalline cellulose was hydrolyzed with sulfuric acid (Seaman hydrolysis) (Selvendran and O'Neill, 1987) and the resulting monosaccharide quantified with a colorimetric assay (anthrone assay). Sugars extracted include rhamnose, arabinose, mannose, galactose, glucose, xylose, and arabinose. Levels of sugars are crop dependent and only whole plant switchgrass samples were analyzed for cellulosic ethanol potential. The matrix polysaccharide sugar composition gives indications about the presence and abundance of wall polymers. In the grasses, arabinose and xylose represent the hemicellulose arabinoxylan, mannose, the occurrence of gluco-mannan, and glucose represents the presence of amorphous cellulose.

Statistical Analysis

The experiments at all locations were established in a randomized complete block design (RCBD) with six replications at LC and UP while MSU had four. Crop yield data analysis was conducted separately for each crop by year due to differing environmental conditions in 2007 and 2008. Gravimetric ethanol, total oil, FAME, and cellulose component yields were determined using a two year average to determine significance. Analysis of variance (ANOVA) was performed on crop yield and fuel quality and quantity using PROC MIXED in SAS (SAS Institute, 2009). The location treatments are considered fixed effects while blocks are considered a random effect. Results are based on the statistical model $y_{ij} = \mu + \text{Location}_i + \text{Block}_j + e$. Normality of residuals was assessed using

PROC UNIVARIATE and Levene's test was used to test homogeneity of variances. When significant effects of treatment occurred, means were compared using Fisher's Protected Least Significant Difference (LSD). Unless otherwise stated, differences are considered significant at an alpha level of 0.05.

Economic Analysis

Enterprise budgets and machine and work rates estimates were based on Stein (2009). Seed prices were based on actual prices of purchased seed in 2007 and 2008. Fertilizer costs and herbicide prices were determined by Jorgensen Farms Elevator (Williamston, MI). Commodity prices were determined by National Agricultural Statistics Service for October 2008 (NAAS, USDA, 2008).

RESULTS AND DISCUSSION

Environmental Conditions

In 2007, precipitation at MSU was below average during the month of July (Table 3.5) and rain received late in the season slowed crop drying. In 2008, precipitation received during seedling establishment was below the 30-year average and rain received late in the season again slowed crop drying.

Table 3.5. Total monthly precipitation (cm) at MSU (East Lansing, MI), LC (Lake City, MI), and UP (Chatham, MI) in 2007-2008. Long-term means (1970-2000) included for comparison.

Location	Year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
MSU	2007	5.6	6.6	9.7	8.9	1.2	14.0	5.3	10.3
	2008	4.0	4.3	3.0	11.3	7.6	1.7	18.6	4.1
	30 yr.	5.7	7.5	7.5	9.3	7.9	7.8	6.3	5.5
LC	2007	8.1	5.8	3.5	6.0	4.3	5.8	4.1	5.9
	2008	4.7	8.9	4.6	18.2	10.0	5.5	7.5	6.8
	30 yr.	4.3	7.3	6.8	7.9	8.3	7.7	8.3	6.8
UP	2007	10.3	16.3	5.5	5.2	4.4	2.0	12.5	13.3
	2008	5.4	16.0	9.3	9.8	4.5	2.7	9.6	5.9
	30 yr.	6.3	8.0	6.5	7.4	8.8	8.4	10.2	9.5

In 2007, LC and UP experienced droughty conditions during critical crop growth and grain filling periods. At UP, rainfall was unevenly distributed during most of July, with very little rain received over a 44-day span from July 15 to August 27, resulting in drought conditions. At LC, starting the same day, droughty conditions spanned a 35-day period to August 18. Weather patterns were slightly different in the southern part of the state at MSU as the site experienced only a span of 25-days, lasting from June 28 to July 22, of less than 0.2 cm of rainfall. In 2008, precipitation at MSU and LC was closer to average than 2007. MSU and LC experienced abundant rainfall in June. At UP in 2008, rainfall was abundant in April during crop emergence and conversely was scarce during crop reproductive and grain filling stages.

In 2007, monthly temperatures at MSU, LC, and UP were slightly above average (Table 3.6).

Table 3.6. Average monthly air temperatures (°C) at MSU (East Lansing, MI), LC (Lake City, MI), and UP (Chatham, MI) 2007-2008. Long term means (1970-2000) included for comparison.

Location	Year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
MSU	2007	3.7	7.1	15.6	19.8	20.6	21.4	17.6	7.1
	2008	-0.2	9.9	12.6	19.6	21.5	20.7	17.4	9.7
	30 yr.	0.6	7.9	13.8	19.4	21.4	20.7	16.5	11.0
LC	2007	2.7	5.6	14.9	19.0	19.9	20.5	17.3	13.0
	2008	-2.0	8.7	10.4	18.0	20.1	19.7	16.4	8.8
	30 yr.	-2.6	5.8	12.1	17.2	19.6	18.5	14.2	8.6
UP	2007	-0.6	3.0	12.3	17.2	19.1	18.3	14.9	10.6
	2008	-5.3	3.9	8.2	15.4	18.4	17.9	14.1	7.3
	30 yr.	-3.1	3.9	11.1	16.1	18.6	18.1	13.9	7.8

Air temperatures recorded at MSU were below the 30-year average during the months of April, July, and October. Temperature at LC were cooler in April, and colder in both March and April at UP. Temperatures in 2008 were different between sites since MSU and LC experienced higher temperatures than normal while they were cooler at UP. The 30-year means were surpassed in all months at MSU with exceptions of March, May, and October and at LC in all but March and May. UP recorded cooler temperatures only in September.

Crop maturity can be predicted using daily average high temperatures and low temperatures to calculate Growing Degree Days (GDD). GDD are calculated as the average of daily high and low temperatures less a base temperature of 10°C. In 2007, temperatures were on average warmer (Table 3.6) and more GDD were accumulated (Table 3.7) than in 2008 at all locations.

Table 3.7. Monthly and yearly accumulation of Growing Degree Day units at MSU (East Lansing, MI), LC (Lake City, MI), and UP (Chatham, MI) during 2007 and 2008, calculated using a base temperature of 10°C.

Location	Year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Total GDD
MSU	2007	26.4	38.4	176.4	295.6	326.4	354.1	230.2	140.4	1587.9
	2008	0.1	68.9	85.8	286.9	356.8	330.0	222.8	53.2	1404.6
LC	2007	14.7	22.4	155.5	269.6	312.4	324.6	218.6	128.7	1446.6
	2008	0.0	62.2	40.4	240.6	310.9	302.0	192.8	37.1	1186.1
UP	2007	1.6	14.3	102.9	219.4	281.0	257.0	153.8	77.4	1107.4
	2008	0.0	7.6	15.6	163.4	260.9	244.1	123.9	20.6	836.1

In 2007, MSU accumulated 1588 GDD while LC and UP accumulated 1447 and 1108 GDD, respectively. Results for 2007 indicate MSU accumulated 9% more GDD than LC and 30% more than UP. In 2008, MSU accumulated 1404 GDD while LC and UP accumulated 1186 and 836 GDD, respectively. Results for 2008 indicate MSU accumulated 16% more GDD than LC and 40% more than UP. Summed GDD over both years indicated dissimilar conditions at MSU, LC, and UP. MSU accumulated 12% and 35% more GDD than LC and UP, respectively. LC accumulated 26% more GDD than UP. Locations which receive more GDD have the potential to achieve higher yield totals (Swanson and Wilhelm, 1996). Given that GDD accumulations were dissimilar at the three sites, temperature could have had a significant effect on yield differences.

Agronomic Yield

Differences among sites included climate, soil type, shading, crop demands, and logistics required differing harvest dates (Table 3.4). Canola, on average, contains 40% oil, making the seed a very attractive food and energy source for birds, in particular the American Goldfinch (*Carduelis tristis* L.). In 2008, swathing canola before it reached physiological maturity resulted in 5% higher yields (S. Smith and K. Thelen, unpublished data). Canola was swathed when 60-75% of the seeds were black and contained 30-40% moisture as recommended by Oklahoma State University Extension (2007). To protect sunflower crop yield in both years, plots were hand harvested and dried when they had reached fully physiological maturity (R9) but had not yet dried to acceptable mechanical harvest moisture percentages or storage moistures of 9.5%.

Statistical analysis determined that blocking within locations was not a significant factor ($p > 0.05$). Therefore, crop yield totals from all plots per crop were averaged to determine a yield mean for each location. MSU, LC and UP yield means differed ($p < 0.05$) in both years (Table 3.8).

Table 3.8. Mean crop yields of bioenergy crops in 2007 and 2008 at MSU (n=4), LC (n=6), and UP (n=6). Means within a year and crop followed by a common letter are not different at ($p < 0.05$) using Fisher's Protected Least Significant Difference test.

Crop	Yield (Mg ha^{-1})					
	2007			2008		
	MSU	LC	UP	MSU	LC	UP
Corn	4.87 a	7.56 a	3.85 b	9.89 b	11.39 a	5.53 c
Soybean	1.83 a	2.17 a	1.16 b	2.10 a	1.74 b	0.75 c
Sunflower	2.54 a	2.43 a	‡	2.70 b	3.83 a	‡
Canola	†	0.36 b	1.26 a	†	1.38 b	1.87 a
Switchgrass	0.61 b	4.41 a	#	7.39 b	11.71 a	8.46 b

†Yield data not computed due to wildlife damage; samples retained for quality analysis.

‡Crop was not planted.

#Crop was not harvested.

In 2007, grain yield of corn and soybean at MSU and LC did not differ yet UP yielded less than both locations ($p<0.05$). MSU yielded 21% while LC yielded 49% more corn grain than UP. Sunflower yield was essentially the same MSU and LC. Canola yielded 71% more seed at UP compared to LC. LC yielded 86% more switchgrass biomass than MSU.

In 2008, MSU significantly yielded 17% more soybean than LC and 64% more than UP. UP soybean yield was substantially less than LC yield by 57%. MSU corn grain yield was 13% lower than LC yield, yet was significantly higher than UP. UP yielded 51% less corn grain than LC. LC significantly yielded 30% more sunflower than MSU. Canola yield was 26% higher at UP compared to LC. Canola yield at MSU was destroyed by wildlife. Switchgrass at LC significantly yielded 37% more biomass than MSU and 28% more than UP. Switchgrass stand establishment at LC was favorable. Lower weed density at LC lead to higher biomass yield as switchgrass did not have to compete with weed species for resources. In 2008, yields overall were higher at LC as compared to MSU and UP as LC yielded significantly more corn, sunflower, and switchgrass.

Lower soybean yield (Table 3.8) was inversely related to latitude (Figure 3.1) with MSU yielding 2.10, LC 1.74, and UP 0.75 Mg ha^{-1}.

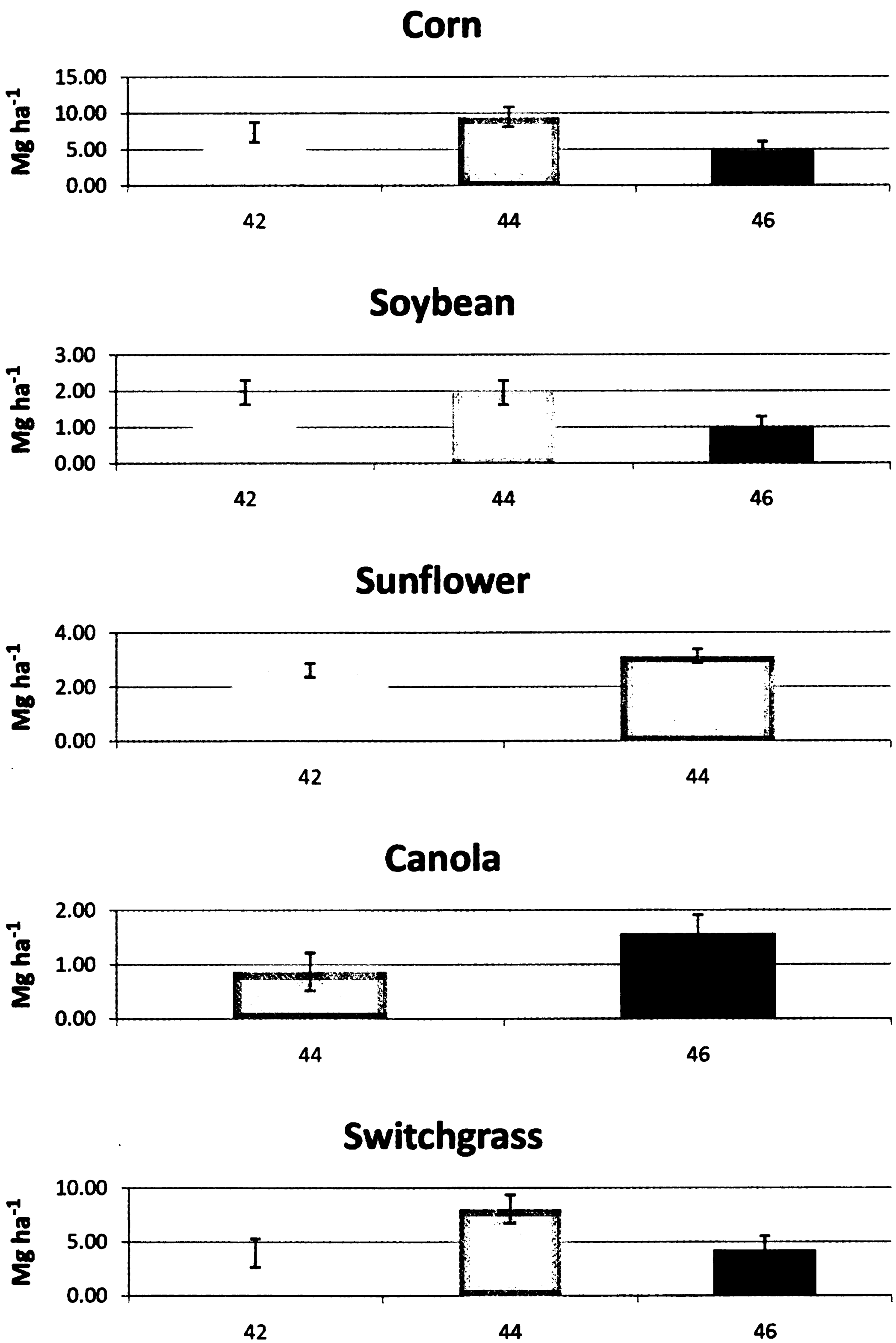

Figure 3.1a-e. Crop yield response and standard errors (α=0.05) at three latitudes 42°N (MSU), 44°N (LC), and 46°N (UP).

Canola yield responded positively to northern, cooler environmental conditions as UP returned significantly higher yields (Table 3.8). These results indicate canola is a candidate biodiesel crop to be planted in northern climates while soybean should be planted in southern climates. Switchgrass returned higher biomass yield at the two northern sites, but showed elasticity across latitudes. Corn yield is limited by latitude and is not considered an optimal bioenergy choice for northern climates. Sunflower seems to be a candidate for bioenergy production based on yield; however the high market value of sunflower could make it an unprofitable feedstock source of biofuel (Nelson et al., 1994).

Marginality of land for production of biofuel is not limiting. Latitude effects are crop specific. If a given crop is planted at a given latitude, marginal land yield is suitable for bioenergy feedstock production. The MSU site is part of a traditional cropping system not limited by marginal soil conditions or latitude. Favorable conditions at MSU should support optimum yield. In 2007, MSU recorded yields which were consistently higher than UP. Yields were comparable between MSU and LC with LC returning higher switchgrass biomass yields. MSU had the highest soybean yields while UP had the highest canola. Based on two years of yield data, marginal land supports bioenergy crop production.

Corn Grain Ethanol Yield

Gravimetric fermentation of corn grain is industry protocol for ethanol production. Ethanol yields were averaged over 2 years for MSU, LC, and UP

(Figure 3.2). Ethanol yields at MSU, LC, and UP of 0.453, 0.433, and 0.398 L ethanol/kg corn were all significantly different. MSU and LC yields were consistent with industry average yields of 0.417 L/kg (Bothast and Schlicher, 2004).

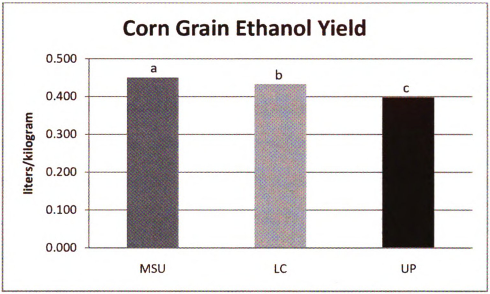

Figure 3.2. Two-year average corn grain ethanol yields at MSU, LC, and UP, 2007 and 2008 data combined; means followed by a differing letter are statistically significant at a $p < 0.05$ using Fisher's Protected Least Significant Difference test.

Factors that influence the ethanol yield potential of corn grain are difficult to use as yield predictors because they are not well understood. Dein et al. (2002) found that the starch content of corn did not correlate well with ethanol yields. They suggested that ethanol yield may be affected by climatic conditions and locations. Reicks et al. (2009) found that, when the corn grain filling period was shortened by a killing frost, ethanol yield was significantly reduced. Dissimilar ethanol yields can be explained by differing latitude (Figure 3.1), temperature (Table 3.6), and GDD unit accumulations (Table 3.7). Corn suited for the same maturity zone was used at all experimental locations which could have affected physiological maturity and consequently ethanol yield at northern locations. LC and UP may not have accumulated enough GDD (Table 3.7) to reach maturity.

Fatty Acid Methyl Esters Yield

Biodiesel, which consists of fatty acid methyl esters (FAME), is derived from triglycerides through a process termed transesterification. Following triglyceride extraction, five FAME compounds are of particular interest for biodiesel production, including palmitic C16:0, stearic C18:0, oleic C18:1, linoleic C18:2, and linolenic C18:3 fatty acids. FAME profiles will vary among crops and growing conditions. FAME levels were determined using gas chromatography with a flame ionization detector (CG-FID), with combined two-year results indicating minimal significant differences between MSU, LC, and UP (Table 3.9).

Table 3.9. Results of fatty acid methyl ester (FAME) analysis of oilseed crops at MSU, LC, and UP, 2007 and 2008 dates combined (mean percent of total oil content by weight); % FAME followed by a differing letter within a fatty acid are statistically significant at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

		% fatty acid methyl esters/ml crop oil									
	n	Palmitic		Stearic		Oleic		Linoleic		Linolenic	
Soybean											
MSU	32	11.68	b	5.33	a	24.63	b	50.92	a	7.44	b
LC	48	13.16	a	5.37	a	26.19	a	47.93	b	7.35	b
UP	48	10.24	c	4.52	b	25.57	a	51.08	a	8.59	a
Canola											
MSU	32	5.11	b	2.27	a	60.65	b	22.60	a	9.37	a
LC	48	5.88	a	1.93	b	63.52	a	19.81	b	8.86	a
UP	48	5.08	b	2.32	a	63.93	a	20.19	b	8.49	b
Sunflower											
MSU	32	5.18	a	4.74	a	77.36	a	12.63	a	†	
LC	48	4.66	a	4.95	a	81.07	a	9.24	b	†	

† Sunflower oil does not contain linolenic FAME.

In soybean, the palmitic, stearic, linoleic, and linolenic FAME percentages differed significantly between MSU, LC, and UP, and data were consistent with those determined by Goering et al. (1982). Palmitic acid is the most common saturated fatty acid found in plants (Goering et al.,1982; Kincs, 1985). Because they are highly saturated, palmitic and stearic acids have high viscosity, causing gelling and coagulation problems in diesel engines (Pryde, 1983; Ma and Hanna, 1999); therefore, low levels of palmitic and stearic acid are desirable. Linoleic and linolenic FAME are unsaturated omega-6 fatty acids. Biodiesel with high levels of linoleic and linolenic fatty acids, due to their unsaturation, has reduced storage duration. Given these factors, optimum biodiesel is obtained by optimizing oleic fatty acid levels. MSU soybean produced 1.6 and 0.9% less oleic acid than LC and UP, respectively. In soybean, levels of palmitic and stearic differed as latitude increased, with LC yielding the highest levels and UP recorded the lowest. UP yielded the highest levels of linoleic and linolenic fatty acids (Table 3.9).

Canola oil fatty acid profiles were affected significantly across marginal locations. Izquierdo et al. (2002) found that the oleic: linoleic ratio depends on the temperature during the early stages of oil synthesis in oilseeds. Differences in oleic acid levels were significant: MSU contained the lowest levels with 3.3 and 2.9% less than UP and LC, respectively. Northern locations of LC and UP yielded lower levels of linoleic and linolenic fatty acids compared to MSU (Table 3.9). Mixed results across latitudes were found when comparing palmitic and stearic acid levels. Due the higher levels of oleic and reduced levels of palmitic, stearic, linoleic, and linolenic acids, canola oil resulted from northern locations possessed optimum biodiesel quality.

Sunflower, grown at MSU and LC, yielded approximately equal oleic and stearic fatty acid levels (Table 3.9). Lower levels of linoleic and linolenic fatty acids were produced at LC. Due to the precedence of oleic acid yielding optimum biodiesel, MSU and LC are both considered acceptable for producing sunflower for conversion to high quality biodiesel.

Determining optimum oilseed crops for location-specific management must include consideration of latitude before any confounding marginal soil features. Southern locations in Michigan, based on FAME analysis, are acceptable for sunflower biodiesel production. Northern locations should focus primarily on canola, since oleic acid levels are acceptable and crop yield is competitive. Soybean is well suited to southern locations, based on crop yield and FAME profiles. Soil and agronomic factors including differences in marginal land characteristics such as water holding capacity, fertility levels, and GDD accumulation, can affect fatty acid profiles in oilseed crops (Izquierdo et al., 2002). The differing latitude (Figure 3.1), temperature (Table 3.6) and GDD accumulation (Table 3.7) of the three research locations resulting in differing FAME levels (Table 3.9).

<u>Total Oil Yield</u>

Two-year average total oil quantity for the oilseed crops differed between MSU (n=8), LC (n=12), and UP (n=12) for soybean and canola, but showed no significance for sunflower (Figure 3.3).

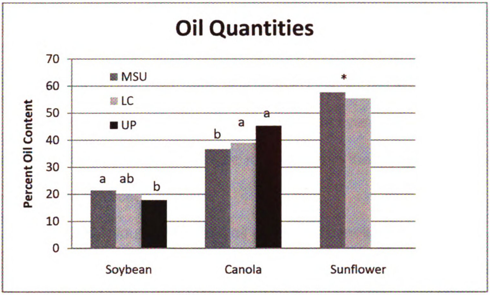

Figure 3.3. Mean total oil content (% by weight) of soybean, canola, and sunflower of oilseed crops at MSU, LC, and UP, 2007 and 2008 dates combined; means followed by a differing letter are statistically significant while * represents no statistical significance at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

Total oil yield of soybean appeared to increase as latitude decreased, ranging from 17.8 to 21.5% of seed dry mass, which is consistent with data reported by Dardanelli et al. (2006). Oil content of soybean differed significantly between locations. Soybean at MSU yielded 21.5% while LC and UP yielded 20.0 and 17.8%, respectively. MSU did not statistically differ from LC, although MSU soybean yielded 7% more oil. Oil content did not differ between LC and UP, but MSU soybean yielded significantly more oil, by 17%, than UP soybean.

Sunflower seed accumulates oil in the final stage of reproductive growth, and oil content can differ with environmental conditions including soil type, shading, agronomic practices, and precipitation (Zheljazkov et al. 2008). Seed oil concentration is important for growers and processors. For example, sunflower crushing plants in North Dakota and Kansas offer a 2% price premium for every 1% oil above 40% (National Sunflower Association 2007). No location differences were observed, with sunflower at MSU yielding 57.6 and LC yielding 55.5% oil. However, these percentages may be slight overestimates because a small fraction of seed coats could not be removed from the samples and was included in the oil extraction process.

Jackson (2000) found that seed oil content of canola was reduced by increasing applications of N fertilizer. At both MSU and ROSE, canola was treated with the same, low-input fertilizer regime with no additional N amendments. Canola total oil content can also be reduced by low levels of precipitation during critical oilseed filling and oil accumulation periods (Chen et al. 2005). Canola at MSU (36.7%) contained significantly less oil compared to LC (39.0%) and UP (45.3%); however, all data fell within the range reported by Sosulskl et al. (1988). Northem, marginal sites appear to be well suited for canola production based on crop yield (Table 3.8), FAME (Table 3.9) and total oil content (Figure 3.3).

Differences in latitude (Figure 3.1), precipitation (Table 3.5), temperature (Table 3.6) and GDD accumulation (Table 3.7) between MSU, LC, and UP affected total oil content. Crop oil content did not appear to be affected by fertility levels. Soybean benefited from southern locations; conversely, canola benefited from northern locations. Sunflower oil content did not differ between MSU and LC. Marginal land sites produced oilseed crops which were comparable to the conventional agronomic site in grain yield as well as total oil content.

Total Crystalline Cellulose Yield

Single year means of crystalline cellulose content of switchgrass differed significantly between MSU, LC, and UP and results were not year dependent (Figure 3.4).

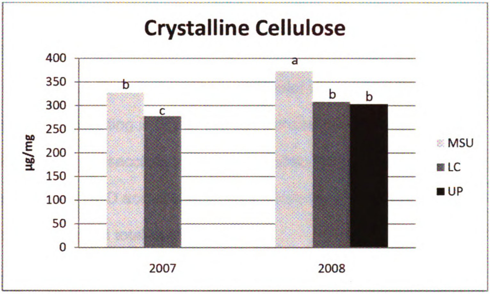

Figure 3.4. Average crystalline cellulose content of switchgrass at MSU, LC, and UP in µg cellulose/mg switchgrass; means followed by a differing letter are statistically significant at $p < 0.05$ using Fisher's Protected Least Significant Difference test.

Switchgrass grown at MSU yielded higher levels of crystalline cellulose compared to LC and UP in 2007 and 2008. Stand age may influence cellulose content (Gomide, 1969). MSU yielded 12% less cellulose in 2007 than in 2008. Crystalline cellulose levels in all second-year switchgrass stands, LC and UP in 2008 and MSU 2007, were not significantly different (Figure 3.4). In 2007, first-year stands at LC produced switchgrass with the lowest crystalline cellulose content at 277.8 µg/mg, while switchgrass at MSU in 2008 was the highest yielding at 373.1 µg/mg. Marginal land characteristics did not appear to have an effect on differences in cellulose content.

Switchgrass is a photoperiod-sensitive plant. Switchgrass cellulose concentration and composition can be influenced by many environmental factors (Moser and Vogel 1995). Temperature is the environmental factor that most strongly affects plant cell walls, with high temperatures causing increased rate of reproductive maturation. Temperature and water stress can affect morphological development by resulting in higher cell wall concentrations, with increases occurring in both polysaccharide and lignin fractions (Buxton and Fales, 1994). Temperature and GDD accumulation were dissimilar at the three locations and could have influenced total cellulose content.

Patton and Gieseker (1942) reported differences in cellulose and lignin content depending upon maturity as well as grass species. Switchgrass grown at MSU was established one year prior to LC and UP plots. A more mature stand of switchgrass is more competitive with annual weed species, and the higher purity of the switchgrass stand likely resulted in higher crystalline cellulose content. In addition, different sampling practices were employed in the two years. Taking into account stand age and sampling practices, total cellulose content at MSU, LC, and UP was similar when equal maturity switchgrass samples were compared.

Total Fuel Yield

Total fuel yield from each crop and location was determined by total crop yield and quantity of fuel produced (Table 3.10).

Table 3.10. Total fuel yield from crops grown on marginal sites (LC and UP) compared to a traditional cropping system (MSU).

Crop	Fuel Yield (kg ha^{-1})[1]					
	2007			2008		
	MSU	LC	UP	MSU	LC	UP
Corn	2200	3300	1600	4500	5000	2100
Soybean	380	390	210	460	380	130
Sunflower	1500	1400	‡	1500	2100	‡
Canola	†	140	510	†	630	940
Switchgrass[2]	200	1200	#	2800	3600	2600

†Fuel yield not computed; wildlife damage.

‡Fuel yield not computed; crop was not planted.

#Fuel yield not computed; crop was not harvested.

[1]Fuel yield assumes 100% recovery

[2]Total crystalline cellulose reported in kg ha^{-1} due to various cellulosic ethanol conversion practices

In both years, corn at MSU and LC yielded higher more ethanol than oilseed crops. At UP in 2008, switchgrass following the establishment year yielded more fuel than corn. Sunflower yielded the most fuel of all oilseed crops at MSU and LC, while canola was best suited at UP. However, biodiesel levels were not comparable to those of ethanol produced from corn and switchgrass. Biodiesel produced from oilseeds is more energy-dense than ethanol from grain or biomass due to high concentrations of available carbon (Shapouri et al., 1995;

Hill et al., 2006). Based on preliminary results, in locations where soil and climatic conditions are marginal, a perennial biomass crop may yield more fuel than intensively managed annual crops.

Economic Analysis

Producers planning to implement bioenergy cropping rotations in their farming operations will make decisions based ultimately on optimizing economic returns. Under marginal land conditions, positive economic outcomes will be possible if the input costs are limited.

Table 3.11. Economic return utilizing marginal land (LC and UP) compared to traditional (MSU) cropping system acreage.

Crop	Economics					
	2007			2008		
	MSU	LC	UP	MSU	LC	UP
Corn	-	+	-	+	+	+
Soybean	-	+	-	+	+	-
Sunflower	+	+	X	+	+	X
Canola	X	+	+	X	+	+
Switchgrass	-	-	-	+	+	+

- Represents an economic net loss
+ Represents an economic net gain
X Indicates the crop was not harvested

Returns from corn, soybean, and sunflower at MSU will provide a financial gain. Canola returns suffered from wildlife damage. Sunflower, at MSU and LC, was profitable in both years. Corn and soybean were consistently profitable at LC; at MSU, these two crops produced an estimated net loss in 2007 probably because of weeds limiting available water. At LC, all crops returned economic gain with exception of switchgrass in the establishment year. UP did not consistently provide economic gain for soybean and corn. Although, switchgrass does not currently have market value as a bioenergy crop, however \$41.50 Mg^{-1} (dry weight basis) price projections were adapted from Sokhansanj et al. (2009). Production and economic analysis of a perennial crop lends to high inputs in the establishment year and decreasing inputs in subsequent years. Switchgrass, following the establishment year, indicated a profit. Agronomic and management practices need to be refined for all bioenergy crops to be profitable under marginal conditions. Under ideal field conditions, all crops have the potential to be profitable. More years of research are needed to allow modeling for economic analysis.

Determining the optimum bioenergy crop to be grown for profit on marginal land is not clear-cut. Currently, cellulosic ethanol is not commercially produced in the U.S. McLuughlin and Kszos (2005) have reported that the economic return of ethanol production from lignocellulosic sources surpasses that of annual crops. Under current industry practices, and given environmental conditions at LC and UP during 2007 and 2008, the greatest economic return was obtained from canola and corn. Once cellulosic production technologies are refined, switchgrass production on marginal sites may prove to return the highest economic gains.

CONCLUSIONS

The LC and UP marginal land sites provided bioenergy crop yield and quality similar to that from traditionally cropped land, indicating the potential for similar marginal sites across the Midwest to also be viable options for bioenergy production. Fuel quantity and quality including ethanol, total oil, crystalline cellulose, and FAME produced from marginal sites showed minimal differences when compared to areas with traditionally high fertility. Preliminary economic analysis supports potential investment in economic endeavors on marginal acreage. Perennial cellulosic crops such as switchgrass hold great promise for production on marginal land sites where water availability and soil fertility will limit yield of annual crops. Increasing available feedstock for energy production on alternative production sites eases stress on market demand for food crops. However, expansion of cropping systems into marginal land needs to be approached with caution to avoid disrupting environmentally sensitive acreage and ecosystems.

APPENDICES

Appendix 3.1. Economic analysis of MSU in 2007 utilizing actual yields.

	$ ha $^{-1}$				
MSU 2007	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	169	968	581	4623	28
CASH EXPENSES					
Seed	71	287	83	37	92
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	6
Energy	316	386	319	386	782
Machinery and Repairs	217	219	178	213	536
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	1459
REVENUE ABOVE CASH EXPENSES	-522	-48	-73	3836	-1431

Appendix 3.2. Economic analysis of LC in 2007 utilizing actual yields.

	$ ha $^{-1}$				
LC 2007	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	14636	1538	783	4419	164
CASH EXPENSES					
Seed	71	287	83	37	92
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	6
Energy	316	386	319	386	782
Machinery and Repairs	217	219	178	213	536
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	1459
REVENUE ABOVE CASH EXPENSES	13945	523	130	3633	-1295

Appendix 3.3. Economic analysis of UP in 2007 utilizing actual yields.

	$ ha $^{-1}$			
UP 2007	Canola	Corn	Soybean	Switchgrass
TOTAL REVENUE	52	769	263	110
CASH EXPENSES				
Seed	71	287	83	92
Fertilizer	19	70	19	19
Herbicides	43	30	30	6
Energy	316	386	319	782
Machinery and Repairs	217	219	178	536
Labor	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	1459
REVENUE ABOVE CASH EXPENSES	-639	-247	-391	-1349

Appendix 3.4. Economic analysis of MSU in 2008 utilizing actual yields.

	$ ha $^{-1}$				
MSU 2008	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	23	1548	676	1380	338
CASH EXPENSES					
Seed	71	287	83	37	0
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	9
Energy	316	386	319	386	36
Machinery and Repairs	217	219	178	213	140
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	229
REVENUE ABOVE CASH EXPENSES	-668	532	22	593	109

Appendix 3.5. Economic analysis of LC in 2008 utilizing actual yields.

	$ ha $^{-1}$				
LC 2008	Canola	Corn	Soybean	Sunflower	Switchgrass
TOTAL REVENUE	571	1785	563	7623	533
CASH EXPENSES					
Seed	71	287	83	37	0
Fertilizer	19	70	19	70	19
Herbicides	43	30	30	56	9
Energy	316	386	319	386	36
Machinery and Repairs	217	219	178	213	140
Labor	25	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	787	229
REVENUE ABOVE CASH EXPENSES	-120	769	-91	6836	304

Appendix 3.6. Economic analysis of UP in 2008 utilizing actual yields.

	$ ha $^{-1}$			
UP 2008	Canola	Corn	Soybean	Switchgrass
TOTAL REVENUE	775	1331	97	351
CASH EXPENSES				
Seed	71	287	83	0
Fertilizer	19	70	19	19
Herbicides	43	30	30	9
Energy	316	386	319	36
Machinery and Repairs	217	219	178	140
Labor	25	25	25	25
TOTAL CASH EXPENSES	691	1016	654	229
REVENUE ABOVE CASH EXPENSES	84	315	-557	122

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Chapter 4. Green Peach Aphid (*Myzus persicae* Sulzer) Response to Increased BioEnergy Crop Production

ABSTRACT

Increasing alternative crop production for biofuels could create agronomic pest related issues for established cropping systems. Canola (*Brassica napus* L. var. *napus*) is a promising oilseed crop anticipated to be used for biodiesel production due to its high oil content, and in particular, monounsaturated oleic acid. There is concern the insect pest green peach aphid (*Myzus persicae* Sulzer) (GPA) due to its polyphagy and particularly due to its ability to serve as a disease vector for the viruses alfalfa mosaic virus, beet necrotic yellow vein, beet western yellows virus, cucumber mosaic virus, impatiens necrotic spot virus, and tomato spotted wilt virus will negatively impact other established cropping systems. Canola fields in Michigan as well as greenhouse studies were sampled to determine if canola would serve as a host to GPA which can transmit various viruses. In 2007, 2008 and 2009, GPA presence was determined by visual observation and canola tissue samples were analyzed for the six listed viruses. Visual observations did not detect GPA. Furthermore, canola tissue samples were negative for the presence of all viruses regardless of location or fertility regime. Additionally, a greenhouse experimental control with aphid cages also detected no virus presence. These results suggest that with appropriate scouting for GPA and potentially vectored viruses, canola production could be expanded in the Great Lakes Region with minimal risk to other crop species.

INTRODUCTION

The public demand for renewable fuels and energy efficient crops has once again spurred interest in using canola (*Brassica napus* L.) for biodiesel production in Michigan (Copeland, 1998). Canola was utilized during World War II and the 1973 Energy Crisis, as an oilseed crop in biodiesel production (Ramadhas et al., 2004). Canola seed content averages 40% oil and 23% protein (Oplinger et. al, 1989) while its immediate counterpart soybean (*Glycine max* (L.) Merrill) is inversely composed of 20% oil and 40% protein. Canola was the first crop, due to high oil content, used for transesterification in the production of biodiesel (Mattson et al., 2007). Soybean has been utilized for biodiesel production in the U.S. due to its availability, ease of management and production in the Midwest, as well as the nitrogen fixation by legumes (Mattson et al., 2007). Conversely, canola oil is better suited than soybean oil for production of quality biodiesel as 60% of the oil is comprised of monounsaturated oleic acid and demonstrates better stability and winter operability (Puppan, 2002). Canola is the biggest source of feedstock for biodiesel production in the world and has become more attractive as rapeseed breeders have improved yield levels to 2.9 ton oil ha^{-1}, reported in Northern Germany (Puppan, 2002). Rapeseed, including canola, contributes 84% of the raw material in the world used for production of biodiesel while soybean and sunflower only account for 1 and 13%, respectively (Korbitz, 2000).

Renewable fuels, including biodiesel which can be produced from canola, have potential to reduce green house gas emissions (GHG) and global warming potential (GWP) (Griffin and Lave, 2006; Sheehan et al., 1998). Fronning et al. (2008) found fertilization regimes incorporating compost and manure amendments in bioenergy crops can further improve their carbon footprint. Bioenergy cropping systems which employ manure and compost may be better suited for reduction of GHG, but may provide a suitable environment for detrimental insect pests and plant pathogens due to high nitrogen levels (Lampkin, 1990).

Green peach aphid (*Myzus persicae* Sulzer) (GPA) has been noted as a worldwide pest in canola production, thriving in temperate regions, and is considered the most important vector of plant viruses, as its distribution is worldwide (Capinera, 2005). GPA is only one of 4,400 species of aphids in the world and can survive in environments in which the primary host plants (*Prunus* sp.) are absent. GPA are polyphagous (Weber, 1985), having the ability to feed on a wide range of plants, and can survive on secondary hosts including important agronomic crops such as *Brassica*, sugarbeet, sugar cane, tobacco, tomato, and potato (van Emden et al., 1969; Blackman and Eastop, 2000). Research conducted by Buntin and Raymer (1994) indicated GPA is a serious pest of winter canola grown in Georgia. GPA mouthparts have evolved which allow for ingestion of a liquid diet (Auclair, 1963), primarily phloem where most viruses are typically found (Loebenstein, 2001). However, most plant damage does not occur by GPA inflicting cellular damage with piercing sucking mouthparts but rather by vector transmission (Moran and Thompson, 2001). Buntin and Raymer (1994) found aphid injury can include reduced plant height, winter survival, and delayed plant development. In the same three year study in Georgia, they found GPA reduced oilseed yields of canola ranging from 9.9-34.8%. Pilorgè et al. (1997) has documented GPA causing significant yield losses in canola in France and Germany.

GPA has the potential to spread numerous infectious and yield limiting viruses. There is concern the insect pest green peach aphid (GPA) due to its polyphagy and particularly due to its ability to serve as a disease vector for the viruses alfalfa mosaic virus, beet necrotic yellow vein, beet western yellows virus, cucumber mosaic virus, impatiens necrotic spot virus, and tomato spotted wilt virus will negatively impact other established cropping systems.

Alfalfa mosaic virus (AMV) is a virus which primarily infects alfalfa however, it can be prevalent in other leguminous crops. Symptoms include yellow mosaic or calico pattering on leaves and stunted plant growth (Koike and Davis, 2007). The virus is spread by aphids and potentially GPA to other crops including canola, chickpea, and faba bean (Schwinghamer, 2002). Studies have indicated a reduction in fresh weight biomass yield from 5 to 30% in alfalfa with reduction associated with impairment of plant physiology, decreased capacity of nodulation, and an increased susceptibility to winterkill (Tu and Holmes, 1980).

Beet necrotic yellow vein (BNYVV) is a virus transmitted in the soil by the widely distributed fungus *Polymyxa betae* (Keskin, 1964). BNYVV is responsible for a sugar beet disease named rhizomania which consists of a rootlet proliferation which induces a wine-glass-like shaped tap root with reduced sugar contents (Duffus, 1986). Duffus also stated Rhizomania is the most damaging sugar beet virus worldwide. The presence of GPA does not determine infection, but will increase symptoms of the disease.

Beet western yellows virus (BWYV) can limit quality and total yield in canola, sugar beets, and potatoes (Copeland, 1998). Symptoms include yellowing of plant tissue resembling that of nutrient deficiency (Koike and Davis, 2007). Infection of canola by BWYV in combination with direct feeding damage by GPA has the potential to reduce yield as much as 46% under maximum infestation conditions. In the same study, seed oil content was also reduced by as much as three percent (Jones et al., 1997). GPA is considered the most important vector of BWYV (Hertel et al., 2004). Although BWYV is not known to occur in Michigan, the possibility of its occurrence is still of great concern to those in the Michigan sugarbeet industry (Copeland, 1998). BWYV has negative implications for canola production and is increasingly present as GPA populations increase.

Cucumber mosaic virus (CMV) has a broad host range. The disease affects a number of important vegetables and ornamentals including tomato, pepper, cucumber, melons, squash, spinach, celery, beets, and petunia (Tisserat, 2006). Plants infected with CMV will develop a slight yellowing and mottling of the older leaves. Expanding leaves typically become twisted, curl downward, and develop a shoestring appearance. Symptoms of infection include stunting and reduced yield and quality of crop. The disease is spread by aphids and potentially GPA (Nameth, 1995).

Impatiens necrotic spot virus (INSV) can infect over 300 species of plants in the U.S. Symptoms of INSV infection can include stunting, ring spots, brown or purple spots on leaves or stems, stem browning (cankers), flower breaking and death. INSV is typically spread by the western flower thrip (Windham et al., 1998) however should be monitored for spread via GPA.

Tomato spotted wilt virus (TSWV) typically does not infect canola, however it is a concern in other horticultural crops. Plant symptoms can include many brown necrotic spots with the margins of leaves wilting and becoming yellow (Koike and Davis, 2007). TSWV is typically spread by thrips however should be monitored for spread via GPA.

GPA populations may be dependent on fertilizer regimes manipulated by differing management strategies. Soluble nitrogen levels have been shown to positively influence aphid growth and reproduction (Nevo and Coll, 2001). Significantly higher numbers of aphids were recorded in cabbage fertilized with manure when compared to non-fertilized cabbage plants, which is believed to be primarily due to nitrogen availability (Duchovskienė and Raudonis, 2008). Yardim and Edwards (2003) found increased fertilizer use, either organic or synthetic, led to an increase in aphid populations. Interestingly, they also observed aphid numbers were lower in tomato fields fertilized with manure as an organic fertilizer when compared to synthetic fertilizers. They concluded manure amendments may have the ability to reduce aphid pest infestations over the long term.

GPA populations can reach very high densities, particularly on young plant tissue which under given conditions, can result in water stress, wilting, and reduced growth rate of plants (Petitt and Smilowitz, 1982). They found prolonged aphid infestation can cause appreciable reductions in potato yield and biomass accumulation. Additionally, early season infestation can be particularly damaging to potato in particular, even if aphids are subsequently removed. Blemishes on plant tissue resulting from aphid feeding usually take the form of yellow spots and leaf distortions, which are common only on the primary host.

Cellular damage is not the only repercussion of aphids. Honeydew is a complex mixture of nutrients including many free amino acids and amides secreted from the terminal opening of the aphid gut (Way, 1963). Contamination of harvestable plant material can occur on foliage crops infested with aphids and honeydew, also causing loss. In Arkansas, mild winters allow overwintering survival of green peach aphid on spinach, thereby leading to contamination problems with honeydew (McLeod, 1991). Nevertheless, compared with other aphid species, GPA does not produce high amounts of honeydew which can support the growth of sooty mold, *Ascomycete* fungi.

Weber (1985) found GPA tolerates a wide array of different compounds in its polyphagy on over 400 plant species which includes more than 50 families. Additionally, over a three year period, GPA exhibited genetic variability in host plants with high adaptability to sugar beets as well as potatoes. In 1982, Radcliffe concluded GPA serves as the primary vector of three sugarbeet and nine potato viruses and is the single most significant pest of potato in Minnesota.

Narrower row spacing and in-row plant spacing of host crops also increases aphid impact (Sarwar, 2008).

When increasing the total acreage of canola to meet energy needs, it is necessary to consider the negative implications that may affect other cropping systems. GPA is recognized as a pest of sugarbeet (*Beta vulgaris* L.), (Summers, 2005), potato (*Solanum tuberosum* L.) (Radcliffe, 1982), and canola (*Brassica napus* L. var. *napus*) (NDSU, 2009). Sugarbeets account for 25% of the world's supply of raw sugar (Rush et al., 2006). In the U.S., sugarbeets are grown on 441,000 hectares with average annual yields of 27 million tons. Sugarbeet is an established and substantial crop in Michigan, which is the fourth leading producer of sugarbeets in the nation providing 110 million dollars in revenue (United States Department of Agriculture, National Agriculture Statistics Service, 2008). Potatoes are also an important cropping system in the U.S. In 2007, 428,000 hectares were devoted to potato production accruing 3.9 billion dollars. The state of Michigan, though not a leading state in terms of potato production, planted 14,400 hectares grossing 156 million dollars. Canola acreage in the U.S. is currently 409,000 hectares with a national yield average of 1,697 kg ha^{-1} totaling 4 billion kilograms. Revenue generated from canola in the U.S. totaled 276 million dollars. Approximately 94% of U.S. canola production is concentrated in North Dakota, Minnesota, and Montana which also have established sugarbeet and potato industries. Revenue generated from canola grown in Michigan is insignificant on a national outlook (United States Department of Agriculture, National Agriculture Statistics Service, 2008).

Understanding the disease triangle is important when considering the affects of plant pests such as GPA on canola. The disease triangle is a conceptual model which relates the connection between the presence of a susceptible host, a disease causing organism, and ideal environmental or weather conditions. If any one of these three factors are missing, no plant diseases will be found and GPA presence will be insignificant.

U.S. food and energy independence could be attained by efficient crop selection and management for bioenergy production which could include cultivation of canola for conversion to biodiesel. In this study, we sought to utilize existing canola fields under producer management in addition to various university canola trials in the state of Michigan to determine by visual and laboratory analysis if GPA would serve as a detrimental insect pest to canola and subsequently other established cropping industries.

MATERIALS AND METHODS

Canola leaf tissue was collected from five locations across the lower peninsula of Michigan in 2007 and 2008. Sampling locations in 2007 included Missaukee County, 44° 18'N, 85° 12'W, Ingham County, 42° 41'N, 89° 29'W treated with and without anaerobic swine manure applications, Oakland County, 42° 43'N, 83° 37'W, and two locations in Leelanau County, 44° 59'N, 85° 39'W. All locations were managed with fertilizer amendments except for the Ingham County location which employed differing fertility regimes. In 2008, county locations remained the same other than fields in Leelanau County which were not sampled. Aphid presence was determined by visual observations in addition to tissue sampling on 2 July 2007 and 30 June 2008. Time of sample collection occurred when pod, stem, and leaf tissue were green in color and occurred before the plant had reached morphological maturity using Munsell color charts (Munsell, 1977). Sampling was delayed as long as possible to ensure adequate time for infection. Sampling was conducted following a randomized sampling strategy. The sampled leaves consisted of one leaf from the newest growth centrally located on each canola plant. Composite samples for each site were comprised of 20 representative leaves.

To supplement field conditions, canola was also grown in a glass-glazed greenhouse at Michigan State University, Ingham County, 42° 41'N, 89° 29'W in 2009. Canola was protected from pests using aphid cages. Canola grown served as an experimental control to ensure no GPA interference. Leaf samples were collected 35 d after planting, before canola had bolted. One composite sample was collected from the greenhouse study and was comprised of 20 representative leaves.

Leaf tissue samples were processed by Agdia Incorporated (Elkhart, IN) which offers services including crop specific analysis to detect the presence of plant pathogens. The testing service does not have a protocol for canola viruses, however analysis used for sugarbeet tissue samples were employed. The sugarbeet protocol tested for the presence of six common viruses including: AMV, BNYVV, BWYV, CMV, INSV, and TSWV. Tissue sample results for virus presence were compared against a positive control to determine a positive or negative prognosis.

RESULTS AND DISCUSSION

Throughout the growing season and greenhouse growth period, insect scouting indicated no presence of GPA. Rosettes, leaves, and stems did not appear to have damaging physical symptoms. Additionally, no visual confirmation of GPA or subsequent honeydew was found on canola plants throughout the growing season.

Viral analyses for AMV, BNYVV, BWYV, CMV, INSV, and TSWV were all negative compared to the positive control. Tissue sample analysis returned negative results at all locations regardless of management practices, fertility regime, or year.

The absence of GPA in canola cropping systems, regardless of management practices, suggests the promise of canola to become a leading feedstock for biodiesel production. Potentially, GPA could serve as a vector for several detrimental viruses in canola, sugarbeet, and potato, however viruses were not detected in this study.

CONCLUSIONS

GPA is a polyghagous insect pest which feeds on over 400 species of plants encompassing 50 families (Weber, 1985). The ability to shift feeding patterns to various plant species could potentially be troublesome as canola acreage is increased for bioenergy feedstocks. Canola leaf tissue analyses did not show a presence of any tested viruses. This research found GPA was not a pest of canola as field scouting did not determine GPA presence.

Research needs to be conducted to observe interactions between potential bioenergy crops and their affect on traditional agronomic crops. As the biofuel economy gains strength, research will be needed on evaluating comparable crop diseases and relationships with traditional cropping systems. The presence of GPA due to potential increases of canola production for bioenergy production is going to continue to be a point of emphasis which will need to be monitored. These results suggest that canola acreage could be expanded in the Great Lakes Region with minimal risk to other crop species provided scouting for GPA and potentially vectored viruses is implemented.

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