INDUSTRIAL SWEETPOTATOES: A VIABLE BIOFUEL CROP FOR ALABAMA

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INDUSTRIAL SWEETPOTATOES: A VIABLE BIOFUEL CROP FOR ALABAMA

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INDUSTRIAL SWEETPOTATOES: A VIABLE BIOFUEL CROP FOR ALABAMA

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Tyler Anthony Monday, son of Mike Monday and Delora Winfrey was born May 24, 1984 in Guntersville, AL. He has a step-mother, Jana and a step-father Mike. He also has one brother, Jake and a sister-in-law Sara. After graduating from Douglas High School in Douglas, Alabama, he attended Snead State Community College. In August 2004, he transferred to Auburn University where he received a Bachelor of Science degree in Horticulture in May 2007. Upon graduation he entered into graduate school to pursue a Master of Science degree under the guidance and direction of Dr. Wheeler G. Foshee, III. He married Jennifer Leigh Young on April 12th, 2008. While at Auburn, Tyler was employed as a graduate research assistant. He received his Master of Science Degree on August 10, 2009.

THESIS ABSTRACT

INDUSTRIAL SWEETPOTATOES: A VIABLE BIOFUEL CROP FOR ALABAMA

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Field studies were conducted evaluating selected sweetpotato (*Ipomea batatas* (L.) Lam.) cultivars for viability as a biofuel crop in Alabama. Industrial sweetpotato cultivars evaluated were: 'X-1617', 'W-328', and 'Markham' along with 'Beauregard', which is the most common edible-type grown in Alabama. Sweetpotato yield, dry matter and ethanol yield were measured. Sweetpotatoes were bagged according to plot and weighed in the field. Dry matter was determined using a moisture balance. Ethanol yields were established by fermenting samples then analyzing them using high performance liquid chromatography (HPLC). Statistical analysis indicated sweetpotato yield, dry matter and ethanol yield were affected by the cultivar chosen. 'X-1617' and 'Beauregard' had the highest sweetpotato yield as well as the highest ethanol yield.

Field studies were conducted to assess nitrogen requirements of selected sweetpotato cultivars following a cover crop of crimson clover (*Trifolium incarnatum*

L.). Treatments included 0, 45, and 90 lbs./A N behind crimson clover and a conventional bareground treatment receiving 90 lbs./A N. Sweetpotato yields from the treatment receiving 45 lbs./A N behind crimson clover were similar in year one and greater in year two than the conventional treatment. An increase in dry matter of storage roots was observed in all treatments behind crimson clover compared to the conventional rate.

Industrial sweetpotatoes were evaluated to determine in-ground storage viability for prolonging harvest periods and reducing storage costs. A field study with ‘X-1617’ evaluated the following harvest periods: October, November, December, and January. Data collected included sweetpotato yield, dry matter, and soil temperature. As soil temperature decreased, sweetpotato yield and dry matter decreased. Reduced sweetpotato yields were observed in the December and January harvest while a reduction in dry matter was observed in the November, December, and January harvest periods.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Today the U.S. economy is dependent on technologies that rely heavily on fossil energy to produce power, chemicals, fuels, and materials. Biofuels present a promising renewable energy opportunity that could provide an alternative to the use of fossil fuel resources (Pastor et al., 2003). Biofuels such as ethanol and biodiesel are alternative fuels that feature blends of traditional fuels with nontraditional alternatives (Chestnutt, 2007). Ethanol is a renewable transportation fuel made primarily from sugar and starch crops such as corn, sorghum, and sugarcane. In 2007, the U.S. produced more than 6.5 billion gallons of corn ethanol, consuming 2.3 billion bushels, or 24.7% of the country's corn harvest (National Corn Growers Association, 2008). Corn-based ethanol production is expected to exceed 10 billion gallons by 2010. This large and rapid expansion of U.S. ethanol production affects almost every aspect of field crop agriculture, ranging from domestic demand and exports to prices and the allocation of acreage among crops (Westcott, 2007). The livestock industry has already been negatively affected by higher corn prices. Livestock feeding is the largest use of U.S. corn, accounting for 50 to 60% of total corn use (USDA, 2007). As a consequence of these commodity market impacts, farm income, government payments, and food prices also change (Westcott, 2007). In an attempt to improve biofuel production and reduce U.S. dependence on corn as the primary source of U.S. ethanol, the bioenergy sector is determined to find alternative crops and technologies for providing feedstocks for ethanol production. Many speculate that ethanol production from lignocellulosic biomass is the future of the ethanol industry. Lignocellulosic ethanol is generally derived from two sources: waste material from agriculture and forest products, or from energy crops that are grown solely for the purpose of ethanol production (Lynd, 1996). Lignocellulosic ethanol is composed of three major components: cellulose (30-50%), hemicellulose (20-30%), and lignin (20-30%) (Duvernay, 2008). Lignocellulosic biomass may be a valuable resource in the future for the ethanol industry. However, recovering the components in a cost-effective way represents a significant technical challenge (Pastor et al., 2003). While research and development of lignocellulosic conversion processes is essential to U.S. progress towards replacing fossil fuels with alternative energy, emphasis can still be placed on finding alternative and abundant starch and sugar sources where conversion technologies already exist and will not interfere with food and feed production (Duvernay, 2008).

Sweetpotato (*Ipomea batatas* (L.) Lam.) is one of the most important starch-producing crops grown worldwide. The dry matter content in sweetpotato ranges from 21 to 30%, of which about 80% is starch (Zhang and Oates, 1999). Due to ease of cultivation, low fertilizer inputs, high adaptability, and high starch content, sweetpotatoes may offer an alternative feedstock for starch-based ethanol production (Santa-Maria, 2009).

Sweetpotato Production

Sweetpotato is a tender, warm-season vegetable that grows as a perennial in tropical and sub-tropical climates, and as an annual in temperate regions (Swaider and

Ware, 2002). Sweetpotato, a member of the Convolvulaceae family, is native to Central and South Americas with the first recorded use in the U.S. in the early 1600's. Sweetpotatoes thrive under the hot conditions of the southern U.S. but can be grown as far north as southern Michigan (Splittstoesser, 1990). Cultivars vary in color from white to orange and even purple (Kays and Wang, 2002). Several differences are notable between white-fleshed and the familiar orange-fleshed sweetpotatoes grown throughout the southern U.S. In general, white-fleshed types are higher in starch (25% to 40%), less sweet, larger in size, and are not considered a main food-source crop (O'Hair, 1990). Most industrial sweetpotatoes are white-fleshed. Industrial sweetpotatoes are edible but are not palatable due to their high starch content which limits sweetness. Common sweetpotato cultivars grown in Alabama for human consumption include 'Beauregard', 'Hernandez', and 'Jewel'.

Internationally, sweetpotato is the seventh most important food crop in the world (Kays, 2005). However, in the U.S. sweetpotato is used as an occasional vegetable. Due to a wide range of health benefits, the popularity of the sweetpotato has recently risen (Kays, 2005). Total U.S. sweetpotato production was 87,100 acres in 1998 compared to 102,900 acres in 2008. During that same period, market value of sweetpotatoes increased by 40%. Average U.S. farm-gate prices for graded sweetpotatoes in 1998 and 2008 were \$15.30 and \$21.50 (per cwt) respectively (USDA, 2008).

In 2008, Alabama ranked fifth nationally in sweetpotato production with 2,600 acres accounting for \$5.3 million in cash receipts (USDA, 2008). Although U.S. sweetpotato production has been on the rise, production in Alabama has declined. Between 1998 and 2008, Alabama sweetpotato production fell by 28% while prices fluctuated greatly. Alabama sweetpotato prices in 1998 and 2008 were $15.10 and $12.10 (per cwt) respectively (USDA, 2008). Economically, sweetpotato is considered one of the most important vegetable crops produced in Alabama with production centered in Baldwin and Cullman counties (Kemble et al., 2006).

A well-drained soil is the most important cultural concern in sweetpotato production. Flooding can be a severe problem for sweetpotatoes in Atlantic and Gulf Coast states in the U.S. Typical symptoms of flooding injury include visible soft spot, rotted areas, growth of saprophytic fungi on the potato surface, and a noticeable odor of fermentation (Collins and Wilson, 1988). The most productive soils are sandy loam and silt loam soils underlaid by finer textured subsoils (Dainello, 2003). Soils with poor internal drainage or high organic matter can produce rough or odd shaped sweetpotatoes that are damaged by scurf, a fungal disease of sweetpotato that causes black necrotic scabs to develop on the surface of the root (Averre, 2000). Long rotations are commonly used to reduce the incidence of scurf and also infection from Fusarium wilt. Fields that have produced a crop of sweetpotatoes in the past two years, have high nematode populations, and that are grassy or highly eroded are typically avoided (Kemble et al., 2006). Studies conducted at Louisiana State University indicated sweetpotato yield was maintained after 4 years of continuous cropping; however, in succeeding years, yield reductions occurred (Walker and Jenkins, 1986). Before planting, a soil test is conducted to determine soil condition and fertilizer recommendations. The optimum pH for sweetpotatoes is 5.8 to 6.2 (Maynard and Hochmuth, 2007). Under average soil conditions, current fertilizer recommendations for sweetpotato production in Alabama is 80 to 90 lbs. of nitrogen (N), 150 to 160 lbs. of phosphorous (P_2O_5), and 60 to 80 lbs. of potash (K_2O) per acre (Kemble et al., 2006). Fertilizer is applied before or at bedding for proper distribution throughout the bed, avoiding direct contact with newly planted slips to prevent burning of foliage (Thompson et al., 2002).

Although referred to as “seed”, sweetpotatoes are propagated vegetatively from sprouts or slips. The choices of seed stock greatly influence the success of the sweetpotato crop and are usually selected from the previous year’s crop. Seed stock used for slip production is generally true to type, free from disease or insect damage, and has a firm bright flesh. Most sweetpotato producers grow their own slips to control quality, assure timely availability, and reduce production costs. Often, two or more smaller producers grow their slips in a single set of plant beds at one location to reduce costs. Some small commercial sweetpotato producers as well as a few large producers will purchase their slips (Parvin et al., 2001). Several states have sweetpotato foundation programs that provide services to sweetpotato growers. The objectives of these programs are to maintain seed stock quality by assuring that sweetpotatoes are free of serious pathogens and other pests and that they exhibit the characteristics of the cultivar (Dangler, 1994). Researchers at Ishikawa College in Japan reported that virus-free sweetpotatoes yielded 33% more than virus-infected sweetpotatoes (Kano and Nagata, 2006). In Alabama, virus-free indexed slips are available for purchase from the North Alabama Horticulture Research Center located in Cullman, AL.

Before slip production begins, seed stock is commonly presprouted. Presprouting encourages more prolific sprouting of roots and can decrease production costs by decreasing the total amount of seed stock required (Motes and Criswell, 2007). In addition to increasing the number of slips produced, presprouting produces slips faster.

Conditions required for presprouting are similar to those required for curing sweetpotatoes. The procedure involves placing seed stock in a controlled storage area such as a curing room where temperature, relative humidity, and ventilation are carefully controlled. The seed stock is presprouted for 21 to 35 days at 21 to 26 ºC (69.8 to 78.8 °F) with 90% relative humidity (Motes and Criswell, 2007). After presprouting, seed stock is treated with a fungicide dip to control surface infestations of black rot, scurf, and root rot organisms and then placed into slip beds (Motes and Criswell, 2007). Most growers use one of two methods of slip production. Some growers utilize heated beds constructed with masonry, cement, or treated wood walls. In this system, plastic is placed in the bottom of the beds before a layer of bedding material is put down. Seed stock is placed in a single layer two to four feet wide and covered with two additional inches of bedding material. The bed is top-dressed with a general purpose, granular fertilizer and covered with clear or black plastic (Thompson et al., 2002). The plastic is perforated to aerate the soil and prevent carbon dioxide (CO_2) and temperature buildup (Jett, 2006). This method produces slips in seven to eight weeks. Most growers use open field beds which produce slips in nine to 10 weeks after bedding. This is an economical method of plant production for growers who do not plant early. However, open field beds generally produce fewer slips than plastic-covered beds (Granberry et al., 2007). Both bed types should be constructed to allow for adequate drainage. Research has shown that peat-based potting mix produces sweetpotato slips earlier but at a relatively higher cost than traditional sawdust. With an abundance of sawdust, economic factors tend to dictate its use as the bedding material for slip production (Beaulieu and Marsh, 2002).

Each bushel of seed stock will produce 1,000 to 1,500 slips in 10 to 15 square feet of bed area (Thompson et al., 2002). Slips are harvested when they have six to 10 leaves and a strong root system. Slips are usually cut one inch above the bed surface and trimmed to 10 to 12 inches (Thompson et al., 2002). Knives are cleaned with a solution of bleach and water to prevent the spread of diseases from the seedbed into the field. Slips are handled in many different ways. Some producers will set slips immediately, while others will wait a few days depending on weather conditions. Slips are kept cool and dry to prevent them from going through a heat and rotting. If slips are pulled, the roots are dipped in a fungicide to control scurf.

Depending on the location, slips are set in the field from mid-spring to early summer. Land is prepared in advance of planting to allow beds to settle and become firm. Prior to planting, a recommended preemergence herbicide program is used to control various grass weeds that can infest a field. Chemical treatments for broadleaf weeds are not as effective, although there are some available. Sweetpotato transplants are set deep, with at least three nodes below ground level (Granberry et al., 2007). Mechanical transplanters are commonly used to plant large numbers of slips. Typical transplanters plant four to six rows at a time but require excessive labor. Labor requirements for sweetpotato production are about 60 man-hours per acre (Motes and Criswell, 2007). Sweetpotatoes are usually spaced 12 inches apart with 36 to 42 inches between rows. Depending on spacing, 9,000 to 18,140 slips will be required per acre (Maynard and Hochmuth, 2007). Although not a requirement, a light irrigation of 0.50 to 0.75 inches per acre helps establish young slips (Kemble et al., 2006).

Sweetpotatoes are subject to a number of diseases that can cause heavy losses in the field and in storage. The most common diseases are scurf, stem rot, nematodes, black rot, and soft rot. Most diseases are controlled or prevented by following recommended production practices including selecting resistant cultivars, using clean seed stock, and choosing proper fields (Motes and Criswell, 2007). Scurf, black rot, and stem rot usually originate from disease infested seed stock and can be controlled by a fungicide dip before bedding (Motes and Criswell, 2007). Sweetpotatoes are frequently damaged by root-knot and reniform nematodes. Both cause stunting and yield loss; however, root-knot nematodes can cause cracking or internal dark lesions which severely reduce the value of the product (Simonne et al., 2007). Fields known to be infested with nematodes or other sweetpotato pests are avoided.

At least 18 species of insects feed on sweetpotato roots (Granberry et al., 2007). Treatments to control foliar damage are rarely necessary due to the crops vigorous growth; however root growth can be affected with extensive damage to foliage (Kemble et al., 2006). White-fringed beetles, wireworms, flea beetle larvae, and the sweetpotato weevil are the most common pests of sweetpotato (Granberry et al., 2007). Sweetpotato weevils are the most destructive pest of the sweetpotato. Larvae are reared primarily in storage roots and can be transported from one location to another unnoticed (Simonne et al., 2007). Using certified seed, spraying with recommended insecticides and destroying infested plant material help to control and prevent most insect damage (Kemble et al., 2006).

Most sweetpotato cultivars are ready to harvest in 90 to 120 days (Thompson et al., 2002). Small acreage growers use a turning plow or a three-point hitch-chain digger while larger growers use mechanical harvesters specifically designed for digging sweetpotatoes. Mechanical harvesters require very little labor, do not require vines to be cut, and deliver sweetpotatoes directly into containers (Granberry et al., 2007). Following harvest, sweetpotatoes are cured for seven to 10 days to minimize storage losses. Curing is a wound healing process which occurs most rapidly at 27 to 31º C (80.6 to 87.8 °F) at 85 to 90% relative humidity (Sumner, 1984). Curing also protects the roots from many storage diseases and excessive shrinkage while starches are being converted to sugars and other flavor components (Kemble et al., 2006). After curing, sweetpotatoes are kept in storage with temperatures between 13 and 15 ºC (55.4 to 59 °F) at 90% humidity (Kays and Wang, 2002). If temperatures fall below 13 ºC (55.4 °F), chilling injury can occur (Motes and Criswell, 2007). Successful storage of sweetpotatoes begins in the field with good production practices. If severely damaged or poor quality potatoes are placed in storage, poor quality potatoes will be taken out of storage. Storage houses are thoroughly cleaned and disinfected as well as fumigated in areas where sweetpotato weevils are a problem (Granberry et al., 2007). Most properly stored sweetpotatoes will keep successfully for four to seven months. Long-term storage experiments have shown that roots can be stored successfully under proper conditions for up to one year without sprouting (Kays and Wang, 2002).

Sweetpotatoes are washed, graded, and sometimes waxed before being shipped to market. Sweetpotatoes are graded into U.S. Extra No. 1, U.S. No.1, U.S. Commercial, and U.S. No. 2 based on size, condition, and absence of defects (Motes and Criswell, 2007). Following grading, sweetpotatoes are generally marketed in 40-pound (4/5 bushel) boxes. Roots are treated with a fungicide to reduce decay during marketing

(Kays and Wang, 2002). Sweetpotatoes used strictly for ethanol production would not require grading since size and shape would not be important factors.

Cover Crops

Cover crops have become a vital part of any cropping system that seeks to be sustainable. Cover cropping is the practice of growing pure or mixed stands of annual, perennial, or biennial herbaceous plants to cover the soil of cropland for all or part of the year when the soil might otherwise be fallow (Stone, 2005). Before commercial synthetic fertilizers were available, vegetable producers used cover crops to replenish soil nutrients. Cover crops provide soil erosion protection, reduce nutrient leaching, and help with weed suppression and pest management (Dabney et al., 2001). Cover crops can also improve the quality and health of the soil by adding biomass and increasing soil organic matter. The use of legume cover crops as a green manure can be a means of reducing the amount of conventional N fertilizer needed in some cropping systems (Stute, 1995). A green manure is a crop used primarily as a soil amendment and a nutrient source for subsequent crops (Cherr et al., 2006). Crimson clover (*Trifolium incarnatum*) is the most commonly used and most desirable of the clovers grown for a cover crop. Crimson clover, also known as Italian clover, is an annual cool season legume in the Fabaceae family. The leaves are palmately tri-foliate and the heads are deep red and cylindrical in shape. Crimson clover matures and produces more N and dry matter earlier than most other clovers (Larson, 2004). Crimson clover can often provide more than 100 lbs. of N per acre. Green forage of crimson clover normally contains about 0.75 to 1% N while dry forage about 3 to 3.5% N (Ball and Lacefield, 2000). The maximum amount of N is accumulated when crimson cover is allowed to reach the late bloom stage prior to being killed or turned under. For best results, crimson clover is generally incorporated into the soil two to three weeks before the succeeding crop (Sattell et al., 1998). In a study conducted at Oregon State University, ‘Common Dixie’ crimson clover planted in mid-September accumulated a maximum of 157, minimum of 55, and average of 108 lbs. N/acre by mid-April over a five year replicated trial (Sattell et al., 1998). Crimson clover is commonly used as a green-manure crop in pecan and other orchard crops in the southeastern U.S.

Ethanol Production

Ethanol (C_2H_5OH) is a clear, colorless liquid containing a hydroxyl group (-OH) bonded to a carbon atom (Brown et al., 2003). The production and use of ethanol is not a new concept, having been produced and used in the U.S. since the early 1900’s. Ethanol is used in household products and other common items such as distilled vinegar, alcoholic beverages, hand wipes, antibacterial hand sanitizer, and solvents. Ethanol is also used as a biofuel. In fact, Henry Ford and other early automakers thought ethanol would be the world’s primary fuel before gasoline became so readily available (U.S. Department of Energy, 2007a). In Brazil, ethanol is commercially produced from sugarcane. In laboratories, renewable resources like wood chips, corn stover, and switchgrass are being converted into cellulosic ethanol, although this production is not yet commercially viable due to high production costs (Crooks and Dunn, 2006). Corn and sugarcane are currently the most common crops used in U.S. ethanol production, with corn dominating the market. One bushel of corn can produce 2.7 gallons of ethanol although many of the newer ethanol production facilities are exceeding this corn-to-ethanol conversion rate. The chemical configuration of ethanol is the same whether the fuel is made from corn, grain, sugarcane or cellulosic materials.

Corn-based ethanol is produced primarily by dry-mill or wet-mill processing. Although wet-mill facilities were common in the industry's early days, dry-mill facilities now account for 80% of industry capability due to lower investment costs (Crooks and Dunn, 2006). Between 2000 and 2007, the number of ethanol plants more than doubled, and production capacity tripled in the U.S. Dry-mill ethanol plants are optimized to produce ethanol with CO_2 and animal feed as co-products. In dry-mill facilities, corn is ground into coarse flour with water and enzymes, and the mixture is cooked. After the cooking process, yeast is added; the mixture is fermented and becomes "mash." The mash is sent to the distillation system where molecular sieves remove the water to produce 200-proof ethanol. Solids and liquids remaining after distillation of the mash are generally recombined for sale as high-protein animal feed (U.S. Department of Energy, 2007b).

Wet-mill plants primarily produce corn sweeteners, along with ethanol and several other co-products such as corn oil and animal feed. In wet-mills, the corn grain is soaked in hot water to separate the protein and starch. The product is coarsely ground then separated to be processed into corn oil. The remaining slurry is finely ground and separated so the fiber can be blended into animal feed and the starch-gluten mixture can be further processed. The starch is dried to make corn starch or processed into sugars which are fermented to produce ethanol (U.S. Department of Energy, 2007b).

In 2003, the U.S. Department of Agriculture surveyed 21 dry-mill ethanol plants to estimate their production costs, including both variable and capital expenses. The plants produced nearly 550 million gallons of ethanol the previous year. Net feedstock costs for the surveyed plants ranged from 39 to 68 cents per gallon. For cash operating expenses, the average energy expenditure was 17.29 cents per gallon. Labor costs ranged from three to 11 cents, maintenance cost from one to seven cents, and administrative cost ranged from one to 18 cents per gallon of ethanol produced. For capital expense expenditures, new plant construction cost from $1.05 to $3.00 per gallon of ethanol (Shapouri and Gallagher, 2002). Comparison with a 1998 survey of ethanol producers showed that total operating cost had changed very little, but that the average cost of building new plants had dropped, possibly due to economies of scale (Shapouri and Gallagher, 2002).

Ethanol producers face unique distribution challenges. Most ethanol plants are concentrated in the Midwestern U.S., but consumption is high along both the east and west coasts. Ethanol plants distribute their fuel by truck and rail, while larger plants are typically located near waterways where they can ship ethanol by barge. In the future, ethanol could be shipped by pipeline, although many issues would need to be addressed (U.S. Department of Energy, 2007d).

Ethanol is currently available in high and low level blends. E85 is a high level blend used extensively in the Midwest. This blend contains 85% ethanol and 15% gasoline. Currently, E85-capable vehicles known as flexible fuel vehicles (FFVs) are available in a variety of models from U.S. and foreign automakers. Other than slightly lower fuel mileage, motorists will see little difference when using E85 versus gasoline. Fuel mileage is affected because E85 has about 34% less energy per gallon than gasoline. As of early 2007, nearly 1,200 U.S. fueling stations in 40 states offered E85 to the more than five million FFVs on U.S. highways (U.S. Department of Energy, 2007c). E85 typically costs about the same or slightly less per gallon than gasoline. As technology improves and more crops are utilized for ethanol production costs are expected to decrease. Low-level blends of ethanol are currently sold in every state. Nearly one-third of U.S. gasoline now contains up to 10% ethanol to boost octane or meet air quality requirements (U.S. Department of Energy, 2007c). Whether used in low or high level blends, ethanol reduces U.S. dependence on foreign oil as well as decreasing greenhouse gas emissions. Sixty percent of U.S. petroleum is currently imported (U.S. Department of Energy, 2007c). With the U.S. depending heavily on foreign oil, the risk of trade deficits, supply disruption, and price changes are high. Ethanol, on the other hand, is almost entirely produced from domestic crops. In addition, ethanol production helps to support the agriculture industry by providing new jobs in the U.S. and expand crop production acres.

Ethanol Production via Fermentation

Fermentation is the process by which sugars such as glucose, fructose, and sucrose are converted into cellular energy. As a result, ethanol and CO_2 are produced as metabolic waste products (Avers, 1986). Fermentation of sugar and starch to ethanol is a time-proven technology currently providing substantial economic benefits to the farming community (McLaughlin and Walsh, 1998). Materials used to manufacture ethanol by fermentation are classified into three main types of raw materials: sugars, starches, and cellulosic materials. Sugars from sources such as sugarcane, sugar beets, and molasses, can be directly converted into ethanol. Starches from crops such as corn, sweetpotatoes, and other root crops must be first hydrolyzed to fermentable sugars by the action of enzymes. Cellulosic materials such as wood and switchgrass must be converted into sugars generally by mineral acids (Lin and Tanaka, 2006).

Fermentation of starch crops such as sweetpotato is somewhat more complex than fermentation of sugar crops because starch must first be converted into sugar then into ethanol. Starch is first hydrolyzed by adding alpha-amylase to avoid gelatinization, and then cooked at high temperature. Hydrolysis is the chemical reaction that converts the complex polysaccharides in the raw feedstock to simple sugars (Lin and Tanaka, 2006). In the biomass-to-ethanol process, acids and enzymes are used to catalyze the reaction. Once cooked, the liquefied starch is hydrolyzed to glucose with glucoamylase. The resulting dextrose is fermented to ethanol with the aid of microorganisms producing CO_2 as a co-product (Lin and Tanaka, 2006). The current process employed for industrial-scale ethanol fermentation from starchy materials is very effective for fermentation. This process raises starch saccharification efficiency and achieves high levels of ethanol production under complete sterilization of harmful microorganisms. However, production costs are high due to large energy consumption in the cooking process and the addition of large amounts of amylolytic enzymes (Lin and Tanaka, 2006). To help lower costs, non-cooking and low-temperature fermentation is being developed.

Sweetpotato as a Biofuel Crop

Sweetpotato is one of the most capable crops for producing ethanol from biomass due to high starch content and ability to increase in size until harvested (Wu and Bagby, 1987). In 1984, a study was conducted in Muscle Shoals, Alabama to determine the fuel potential of several agricultural crops (Mays et al., 1990). The highest-yielding cultivars of several carbohydrate producing crops were chosen. Crops included in the study were the sweetpotato, Jerusalem artichoke, sweet sorghum, Irish potato, sugar beet, and the fodder beet. Data collected on starch and sugar crops indicated that sweetpotatoes and sweet sorghum had the best potential for ethanol production in the Southeast (Mays et al., 1990). In 2008, the Agricultural Research Service conducted studies in Alabama and Maryland comparing sweetpotato ethanol production to that of corn. Sweetpotatoes grown in both states yielded two to three times as many carbohydrates for fuel ethanol production as corn (ARS, 2008). Sweetpotatoes can yield a very large amount of biomass without the need for high input costs (Yokoi and Saitsu, 2001). Per pound, sweetpotatoes yield some 40 to 50% more starch than corn, Irish potatoes, and wheat (O'Hair, 1990). Per acre, sweetpotato starch productivity is three to four times higher than corn and twice that of cassava (Yokoi and Saitsu, 2001). With regard to ethanol production, sweetpotatoes and require less energy inputs than corn (Yokoi and Saitsu, 2001). Sweetpotatoes also have a good storage life so that an ethanol production facility could be supplied with feedstock over a period of months. The use of staggered planting and harvest dates may also allow ethanol facilities to receive new sweetpotatoes over a longer period of time.

Due to high ethanol yield per acre, sweetpotato could be an ideal crop as an ethanol source for many decades to come, even if viable cellulosic ethanol becomes available. However, because of high production costs mainly associated with labor requirements, sweetpotatoes are still more expensive to produce on a per acre basis than corn. Therefore, the objectives these studies were to: 1) evaluate selected sweetpotato cultivars for suitability for ethanol production in Alabama, 2) evaluate nitrogen fertility needs of selected sweetpotatoes grown with and without crimson clover as a winter cover crop, 3) evaluate in-ground storage techniques to determine storage capability of sweetpotatoes stored in the field.

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CHAPTER II

EVALUATION OF SELECTED SWEETPOTATO CULTIVARS FOR USE AS A BIOFUEL CROP IN ALABAMA

Abstract

Field studies were conducted evaluating selected sweetpotato (*Ipomea batatas* (L.) Lam.) cultivars for viability as a biofuel crop in Alabama. Industrial sweetpotato cultivars evaluated were: ‘X-1617’, ‘W-328’, and ‘Markham’ along with ‘Beauregard’, the most common edible-type grown in Alabama. Industrial sweetpotato cultivars were selected based on their high starch yielding characteristics. Sweetpotato yield, dry matter and ethanol yield were measured. Sweetpotatoes were bagged according to plot and weighed in the field. Dry matter was determined using a moisture balance. Ethanol yields were established by fermenting samples then analyzing them using high performance liquid chromatography (HPLC). Analysis indicated sweetpotato yield, dry matter and ethanol yield was affected by the cultivar chosen. ‘X-1617’ and ‘W-328’ were the highest yielding industrial sweetpotato cultivars tested. ‘X-1617’ produced a maximum of 1219 (WREC 2008), minimum of 604 (SMREC 2008) and average of 890 gal/A of ethanol. These results indicate that industrial sweetpotatoes are suitable for producing large amounts of ethanol without the need for heavy inputs and are viable as a biofuel crop for Alabama.

Introduction

Sweetpotato is a tender, warm-season vegetable that grows as a perennial in tropical and sub-tropical climates, and as an annual in temperate regions (Swaider and Ware, 2002). Sweetpotato, a member of the Convolvulaceae family, is native to Central and South Americas with the first recorded use in the U.S. in the early 1600's. Sweetpotatoes thrive under the hot conditions of the southern U.S. but can be grown as far north as southern Michigan (Splittstoesser, 1990). Cultivars vary in color from white to orange and even purple (Kays and Wang, 2002). Several differences are notable between white-fleshed and the familiar orange-fleshed sweetpotatoes grown throughout the southern U.S. In general, white-fleshed types tend to be higher in dry matter (25% to 40%), less sweet, larger in size, and are not considered a main food-source crop (O'Hair, 1990). Most industrial sweetpotatoes are white-fleshed types. Common sweetpotato cultivars grown in Alabama for human consumption include 'Beauregard', 'Hernandez', and 'Jewel'.

A well-drained soil is the most important cultural concern in sweetpotato production. Flooding can be a severe problem for sweetpotatoes in Atlantic and Gulf Coast states in the U.S. The most productive soils are sandy loam and silt loam soils underlaid by finer textured subsoils (Dainello, 2003). Soils with poor internal drainage and soils high in organic matter can produce rough or odd shaped sweetpotatoes that are damaged by scurf (Thompson et al., 2002). Fields are generally avoided that have produced a crop of sweetpotatoes in the past two years, have high nematode populations, and that are grassy or highly eroded (Kemble et al., 2006). Before planting, soil tests are conducted to determine soil condition and fertilizer recommendations. The optimum pH for sweetpotatoes is 5.8 to 6.2 (Maynard and Hochmuth, 2007). Under average soil conditions, current fertilizer recommendations for sweetpotato production in Alabama is 80 to 90 lbs. of nitrogen (N), 150 to 160 lbs. of phosphorous (P_2O_5), and 60 to 80 lbs. of potash (K_2O) per acre (Kemble et al., 2006). Fertilizer is applied before or at bedding for proper distribution throughout the bed, avoiding direct contact with newly planted slips to prevent burning of foliage (Thompson et al., 2002).

Although referred to as seed, sweetpotatoes are propagated vegetatively from sprouts or slips. The choices of seed stock greatly influence the success of the sweetpotato crop and are usually selected from the previous year's crop. Seed stock used for slip production is generally true to type, free from disease, insect damage, and veins.

Before slip production begins, seed stock is commonly presprouted by placing the stock in a controlled storage area such as a curing room where temperature, relative humidity, and ventilation are carefully controlled. Presprouting encourages more prolific sprouting of roots and can decrease production costs by decreasing the total amount of seed stock required (Motes and Criswell, 2007). After presprouting, seed stock is treated with a recommended fungicide dip to control surface infestations of black rot, scurf, and root rot organisms and then placed into beds (Motes and Criswell, 2007).

Each bushel of seed stock will produce 1,000 to 1,500 slips in 10 to 15 square feet of bed area (Thompson et al., 2002). Slips are harvested when they have 6 to 10 leaves and a strong root system. Slips are cut one inch above the bed surface and trimmed to 10 to 12 inches (Thompson et al., 2002). If slips are pulled, they are dipped in a fungicide to control scurf.

Depending on the location, slips are set in the field from mid-spring to early summer. Prior to planting, a recommended preemergence herbicide program is employed to control various grass weeds that can infest a field. Chemical treatments for broadleaf weeds are not as effective, although there are some available. Sweetpotato transplants are set deep, with at least three nodes below ground level (Granberry et al., 2007). The most efficient method for planting large numbers of slips is with a mechanical transplanter. Common spacing is 12 inches between plants and 36 to 42 inches between rows. Depending on spacing, 9,000 to 18,140 slips will be required per acre (Maynard and Hochmuth, 2007). Although not a requirement, a light irrigation of 0.50 to 0.75 inches per acre helps establish young slips (Kemble et al., 2006).

Most sweetpotato cultivars are ready to harvest in 90 to 120 days (Thompson et al., 2002). Following harvest, sweetpotatoes are cured for seven to 10 days to minimize storage losses then stored at temperatures between 13 and 15 ºC (55.4 to 59 °F) at 90% humidity (Kays and Wang, 2002).

Ethanol (C_2H_5OH) is a clear, colorless liquid containing a hydroxyl group (-OH) bonded to a carbon atom (Brown et al., 2003). The production and use of ethanol is not a new concept, having been produced and used in the U.S. since the early 1900's. Most recently, ethanol has been utilized as a biofuel. In Brazil, ethanol is commercially produced from sugarcane. Corn and sugarcane are currently being utilized in the U.S. to produce ethanol, with corn dominating the market. The chemical configuration of ethanol is the same whether the fuel is made from corn, grain, sugarcane or cellulosic materials.

Fermentation is the process by which sugars such as glucose, fructose, and sucrose are converted into cellular energy. As a result, ethanol and CO_2 are produced as metabolic waste products (Avers, 1986). Fermentation of sugar and starch to ethanol is a time-proven technology currently providing substantial economic benefits to the farming community (McLaughlin and Walsh, 1998). Materials used to manufacture ethanol by fermentation are classified into three main types of raw materials: sugars, starches, and cellulosic materials.

Fermentation of starch crops such as sweetpotato is somewhat more complex than fermentation of sugar crops because the starch must first be converted into sugar before being converted into ethanol. Starch is first hydrolyzed by adding alpha-amylase to avoid gelatinization, and then cooked at high temperature (Lin and Tanaka, 2006). Hydrolysis is the chemical reaction that converts the complex polysaccharides in the raw feedstock to simple sugars (Lin and Tanaka, 2006). In the biomass-to-ethanol process, acids and enzymes are used to catalyze the reaction. Once cooked, the liquefied starch is hydrolyzed to glucose with glucoamylase. The resulting dextrose is fermented to ethanol with the aid of microorganisms producing CO_2 as a co-product (Lin and Tanaka, 2006). The current process employed for industrial-scale ethanol fermentation from starchy materials is very effective. However, production costs are high due to large energy consumption in the cooking process and the addition of large amounts of amylolytic enzymes (Lin and Tanaka, 2006). To help lower costs, non-cooking and low-temperature fermentation is being developed.

Ethanol is currently available in high and low level blends. E85 is a high level blend used extensively in the Midwest. This blend contains 85% ethanol and 15%

gasoline. E85 typically costs about the same or slightly less per gallon than gasoline. As technology improves and more crops are utilized for ethanol production costs are expected to decrease. Low-level blends of ethanol are currently sold in every state. Nearly one-third of U.S. gasoline now contains up to 10% ethanol to boost octane or meet air quality requirements (U.S. Department of Energy, 2007).

In an attempt to improve biofuel production and reduce U.S. dependence on corn as the primary source of U.S. ethanol, the bioenergy sector is focused on finding alternative crops and technologies for providing feedstocks for ethanol production. Due to high starch content and suitability for growth on marginal lands, industrial sweetpotatoes may be viable candidates for ethanol production. Industrial sweetpotatoes also have the ability to increase in weight until they are harvested (Wu and Bagby, 1987). Per pound, sweetpotatoes yield some 40 to 50% more starch than corn, Irish potatoes, and wheat (O'Hair, 1990). Per acre, sweetpotato starch productivity is three to four times higher than corn and twice that of cassava (Yokoi and Saitsu, 2001). With regard to ethanol production, sweetpotatoes and require less energy inputs than corn (Yokoi and Saitsu, 2001). Sweetpotatoes have a good storage life so that an ethanol production facility could be supplied with feedstock over a period of months. With this in mind, the objective of this study was to evaluate selected cultivars of sweetpotato for suitability for ethanol production in Alabama.

Materials and Methods

<u>WREC 2007</u>

A field study evaluating suitable sweetpotato cultivars for ethanol production was conducted in the spring of 2007 (June 15th) at the Wiregrass Research and Extension

Center (WREC) located in Headland, AL. Soil type was a Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) (USDA series description). Cultivars used in the study included: 'X-1617', 'W-328', 'Markham', and 'Beauregard'. Slips for 'X-1617', 'W-328', and 'Markham' were supplied by an independent contractor working for the USDA. 'Beauregard' slips were supplied by the North Alabama Horticulture Research Center (NAHRC) located in Cullman, AL. The soil was prepared and formed into 16 plots consisting of two 25' rows spaced 3' apart. Plots were spaced 10' apart with 25' alleys. Four replications of 'Beauregard' and 'X-1617', three replications of 'W-328', and two replications of 'Markham' were arranged in a randomized complete block design (RCBD). The number of replications was determined by the number of slips available. Two days before planting a preemergence herbicide was applied (Valor, Valent Biosciences, Libertyville, IL) at labeled rates to control annual broadleaf weeds. Fifty slips per plot were planted on a 12" spacing using a mechanical transplanter. Immediately after planting, an additional preemergence herbicide (Command 3ME, FMC Corporation, Philadelphia, PA) was applied at labeled rates to control annual grasses and broadleaf weeds. All P_2O_5, K_2O and half of recommended N fertilizer was applied at planting according to soil test recommendations. The remainder of N fertilizer was applied once vines began to run. Slips were irrigated once immediately after planting, but received no additional irrigation. The sweetpotatoes were harvested using a three-point chain digger on November 19th and were bagged and weighed in the field according to plot. After harvesting, sweetpotatoes were properly cured for seven to 10 days then stored at 15.5 °C (60°F).

<u>WREC 2008</u>

The 2007 field study conducted at WREC was repeated in 2008 using the same cultivars. All slips were produced from seedstock saved from the previous year's study. Four replications of 'Beauregard', 'X-1617' and 'Markham', and two replications of 'W-328' were arranged in a RCBD. Standard production protocol was followed as noted in the 2007 WREC study. On November 4th, the sweetpotatoes were harvested using a three-point chain digger then bagged and weighed in the field according to plot. After harvesting, sweetpotatoes were properly cured for seven to 10 days then stored at 15.5 °C (60°F).

SMREC 2008

A field study evaluating sweetpotato cultivars for ethanol production was conducted in the spring of 2008 (June 17th) at the Sand Mountain Research and Extension Center (SMREC) in Crossville, AL. Soil type was a Hartsells fine sandy loam (fine-loamy, siliceous, subactive, thermic Typic Hapludults) (USDA series description). Cultivars used in the study included: 'X-1617', 'W-328', 'Markham', and 'Beauregard'. Slips for 'W-328' 'X-1617' and 'Markham' were produced in slip beds located at Auburn University. Slips for 'Beauregard' were supplied by the NAHRC. All slips excluding 'Beauregard' were produced from seedstock saved from the previous year's study. The soil was prepared and formed into 14 plots consisting of two 25' rows spaced 3' apart. Plots were spaced 10' apart with 25' alleys. Four replications of 'Beauregard' and 'X-1617' and three replications of 'Markham' and 'W-328' were arranged in a RCBD. Standard production protocol was followed as noted above. The sweetpotatoes were harvested on October 28th using a three-point chain digger. Sweetpotatoes were bagged and weighed in the field according to plot. After harvesting, sweetpotatoes were properly cured for seven to 10 days then stored at 15.5 °C (60°F).

Ethanol and Dry Matter Analysis

To determine ethanol yield, sweetpotatoes were subjected to fermentation and high performance liquid chromatography (HPLC) analysis based on adjusted commercial ethanol production protocol (Broder and Barrier, 1988). Dry matter of storage roots was determined by placing grated sweetpotatoes in a moisture analyzer (Ohaus, Pine Brook, NJ) for 20 minutes at 110°C (230°F). After enzymes were added and the mixture was cooked, each flask was sealed using cotton balls and incubated at 30°C (86°F) for up to 40 hours. Samples were taken at time 0, 20, and 40 hours and analyzed using HPLC to determine ethanol yield.

Data were analyzed with SAS's Proc GLM procedure for ANOVA and Waller-Duncan's K-ratio T Test was used for means separation (SAS Institute, Cary, NC).

Results and Discussion

WREC 2007

Analysis revealed differences for all variables measured. Sweetpotato yield was different by cultivar ($P<0.0001$) (Table 1). 'Beauregard' (48,519 lbs./A) had the highest yield followed by 'X-1617' (37,850 lbs./A). 'W-328' (26,107 lbs./A) and 'Markham' (25,439 lbs./A) had similar yields but were lower than 'Beauregard' and 'X-1617' (Table 1; Figure 1). Ethanol yield was different by cultivar ($P<0.0001$) (Table 2). 'X-1617' had the highest ethanol yield (848.6 gal./A) followed by 'Beauregard' (566.1 gal./A), 'Markham' (545.6 gal./A) and 'W-328' (551 gal./A) which all had similar yields (Table 2; Figure 2). Dry matter was also different according to cultivar ($P<0.0001$) (Table 2).

‘X-1617’ (38.67 %), ‘W-328’ (37.57%), and ‘Markham’ (38.30%) were similar and had higher dry matter than ‘Beauregard’ (26.40%).

WREC 2008

Analysis revealed differences for all variables measured. Sweetpotato yield was different by cultivar (P<0.0001) (Table 3). ‘X-1617’ and ‘Beauregard’ were similar and had the highest sweetpotato yields at 54,387 and 49,455 lbs./A, respectively. ‘W-328’ (38,797 lbs./A) had lower yields than ‘X-1617’ (54,387 lbs./A) but was similar to ‘Beauregard’(49,455 lbs./A) while ‘Markham’ had the lowest yields at 12,494 lbs./A (Table 3; Figure 3). Ethanol yield was different by cultivar (P<0.0001) (Table 4). ‘X-1617’ has the highest ethanol yield (1220.8 gal./A) followed by ‘W-328’ (812.3 gal./A), ‘Beauregard’ (589.5 gal./A), and ‘Markham’ (270.9 gal./A) which were different from each other (Table 4; Figure 4). Differences were also observed for dry matter (P<0.0001) (Table 4). ‘X-1617’ had the highest dry matter at 43.97% followed by ‘W-328’ (38.95%) and ‘Markham’ (40.30%) which were similar. ‘Beauregard’ had the lowest dry matter at 26.60%.

SMREC 2008

As in the previous studies, the 2008 field study conducted at SMREC revealed differences for all variables measured. Sweetpotato yield was different by cultivar (P<0.0001) (Table 5). ‘Beauregard’ yielded more than any other cultivar at 58,086 lbs./A. ‘X-1617’ (30,845 lbs./A) and ‘W-328’ (29,548 lbs./A) had similar yields although much lower than ‘Beauregard’ while ‘Markham’ (20,137 lbs./A) had the lowest yields although similar to ‘W-328’ (Table 5; Figure 5). Analysis also indicated differences in ethanol yield in cultivars tested (P<0.0001) (Table 6). ‘Beauregard’ and

‘X-1617’ were similar and had the highest ethanol yields at 771 and 604.4 gal./A respectively. ‘W-328’ (585.1 gal./A) had slightly lower yields and was similar to ‘X-1617’ while ‘Markham’ again had the lowest yields at 413.2 gal./A (Table 6; Figure 6). Dry matter was different for cultivars tested ($P<0.0015$) (Table 6). ‘X-1617’ (33.45%), ‘W-328’ (34.45%), and ‘Markham’ (33.77%) were all similar and had higher dry matter than ‘Beauregard’ (27.00%).

Discussion

Results from these three field studies revealed that ‘X-1617’, ‘Beauregard’, and ‘W-328’ sweetpotato cultivars are viable as ethanol crops in regards to both production and ethanol yields. The most effective cultivar overall in producing ethanol on a per acre basis was the industrial type ‘X-1617’ which produced a maximum of 1219 (WREC 2008), minimum of 604 (SMREC 2008) and average of 890 gal/A of ethanol for these three studies. A closer look by location showed that ‘X-1617’ produced 50% more ethanol than ‘Beauregard’ in 2007 and 107% more in 2008 at the WREC.

When compared to high yields of corn (200 bu./A) which would produce 450 gallons of ethanol per acre, our highest yielding sweetpotato cultivar ‘X-1617’ produced 49% more ethanol on a per acre basis while requiring less fertilizer and pesticide inputs than that used in corn production. Furthermore, our research was conducted on dry land conditions with the exception of a single post-transplant irrigation as recommended to increase plant survival. It is unlikely that high corn yields (200 bu/A) would be obtained under dry land conditions in Alabama.

Very little published data is currently available in the literature on sweetpotatoes as a biofuel crop. Our studies established that industrial sweetpotatoes can be grown successfully in north, central and south Alabama. Furthermore, these results indicate that the industrial sweetpotato is a viable candidate for ethanol production in Alabama.

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Table 1. Sweetpotato yields for the spring 2007 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Cultivar	Yield (lbs/plot)	Yield (lbs/A)[Z]
Beauregard	164.09a[Y]	48,519a
X-1617	130.33b	37,850b
W-328	89.89c	26,107c
Markham	87.60c	25,439c
Observed P-value (<0.0001)		

[Z]Yield (lbs/A) = lbs/plot * 290.4

[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test (P≤0.05).

Table 2. Sweetpotato ethanol yields for the spring 2007 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Cultivar	% Dry Matter	EtOH (gal/dry ton)[Z]	EtOH (gal/A)
Beauregard	26.40b[Y]	90.14	566.1b
X-1617	38.67a	118.18	848.6a
W-328	37.57a	110.22	545.6b
Markham	38.30a	114.31	551b

[Z]Ethanol yields based on HPLC analysis.

[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Table 3. Sweetpotato yields for the spring 2008 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Cultivar	Yield (lbs/plot)	Yield (lbs/A)[Z]
Beauregard	170.30ab[Y]	49,455ab
X-1617	187.28a	54,387a
W-328	133.60b	38,797b
Markham	43.03c	12,494c
Observed P-value (<0.0001)		

[Z]Yield (lbs/A) = lbs/plot * 290.4

[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Table 4. Sweetpotato ethanol yields for the spring 2008 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Cultivar	% Dry Matter	EtOH (gal/dry ton)[Z]	EtOH (gal/A)
Beauregard	26.60c[Y]	90.14	589.5c
X-1617	43.97a	118.18	1220.8a
W-328	38.95b	110.22	812.3b
Markham	40.30b	114.31	270.9d

[Z]Ethanol yields based on HPLC analysis.

[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Table 5. Sweetpotato yields for spring 2008 cultivar study conducted at the Sand Mountain Research and Extension Center, Crossville, AL.

Cultivar	Yield (lbs/plot)	Yield (lbs/A)[Z]
Beauregard	203.47a[Y]	59,086a
X-1617	106.22b	30,845b
W-328	101.75bc	29,548bc
Markham	69.34c	20,137c
Observed P-value (<0.0001)		

[Z]Yield (lbs/A) = lbs/plot * 290.4

[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

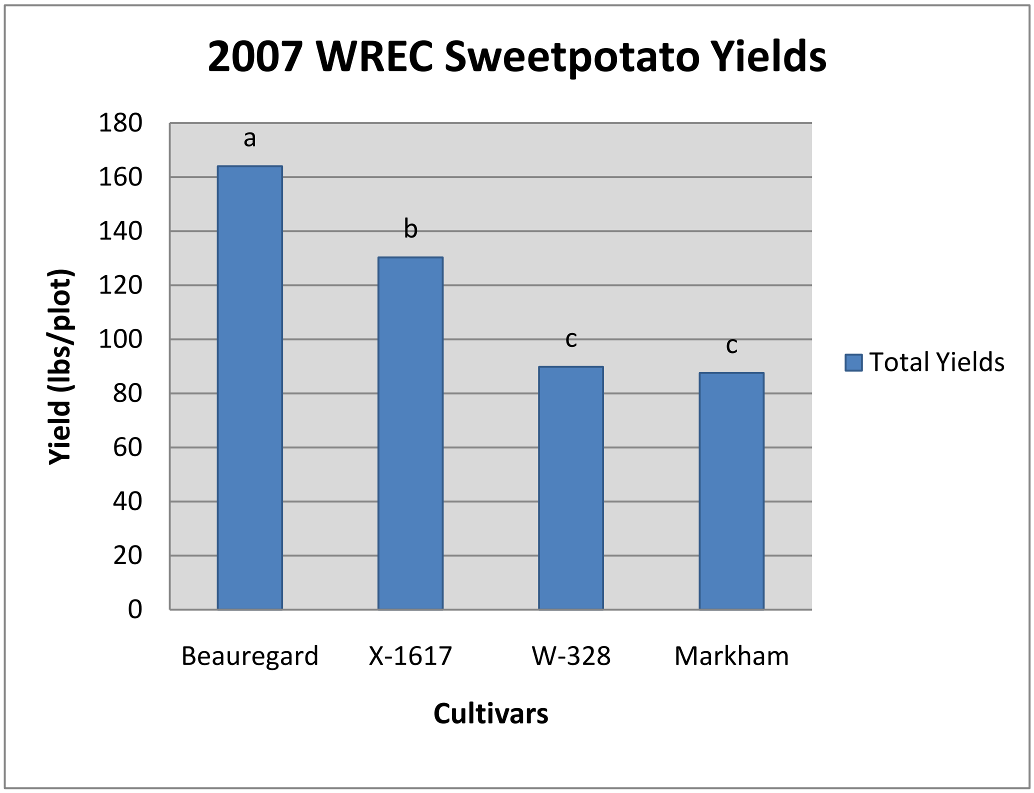
Table 6. Sweetpotato ethanol yields for spring 2008 cultivar study conducted at the Sand Mountain Research and Extension Center, Crossville, AL.

Cultivar	% Dry Matter	EtOH (gal/dry ton)[Z]	EtOH (gal/A)
Beauregard	27.00b[Y]	90.14	771.1a
X-1617	33.45a	118.18	604.4ab
W-328	34.45a	110.22	585.1bc
Markham	33.77a	114.31	413.2c

[Z]Ethanol yields based on HPLC analysis.

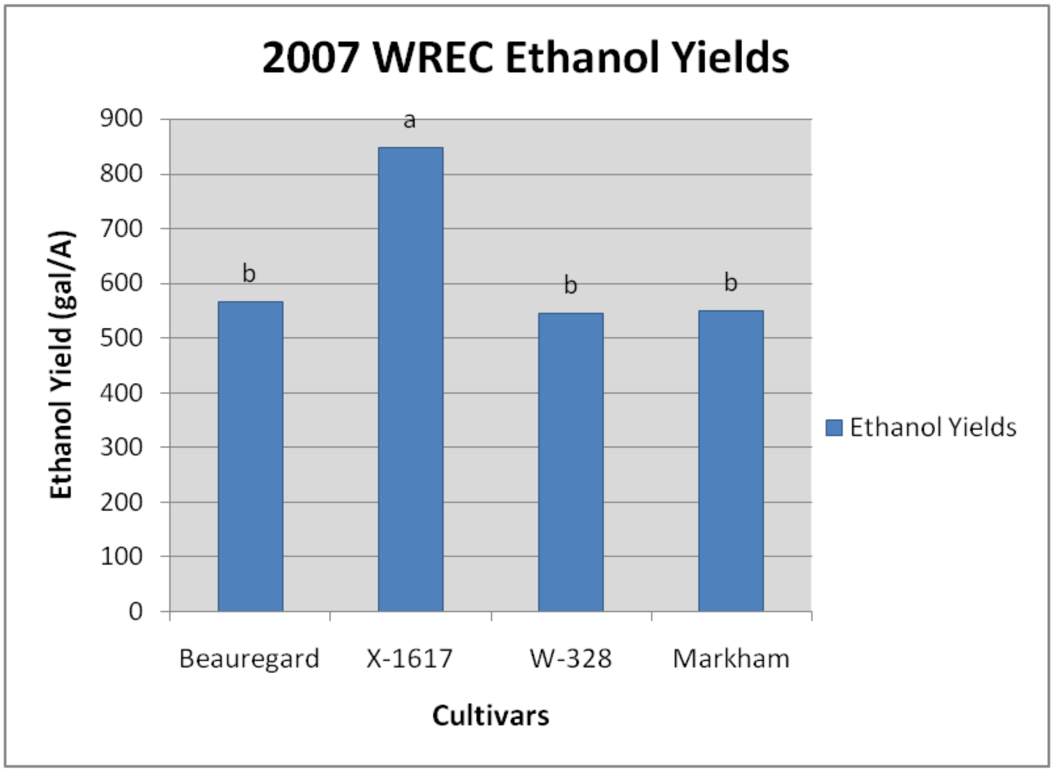
[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 1. Sweetpotato yields for the spring 2007 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.



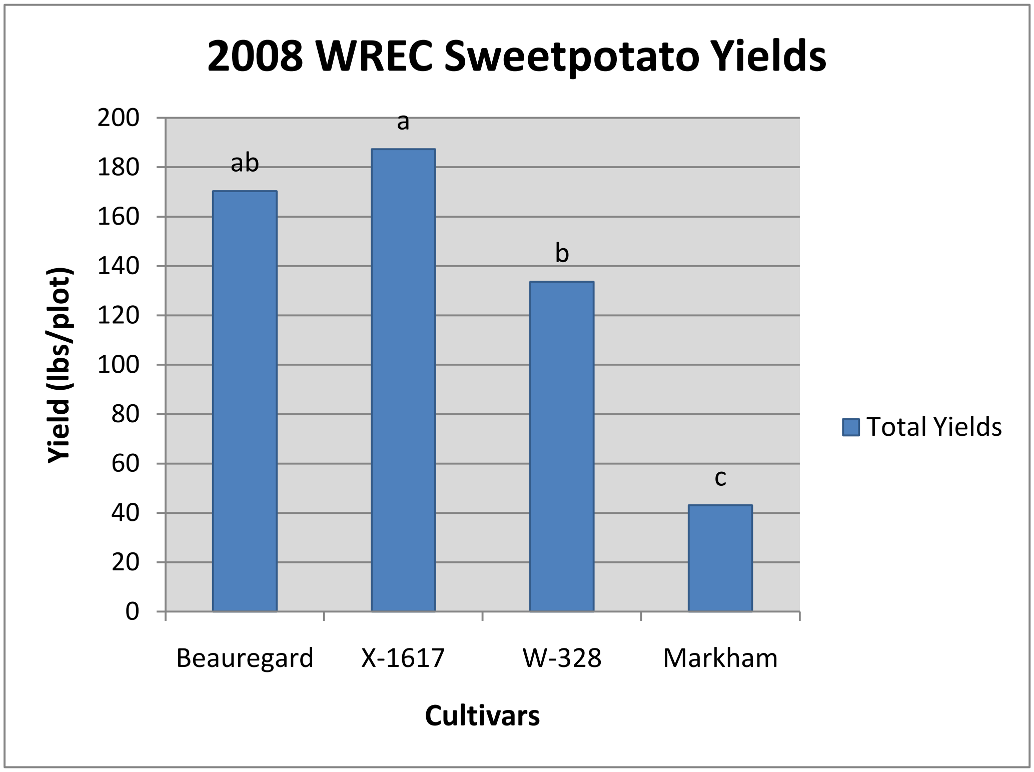
Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 2. Sweetpotato ethanol yields for the spring 2007 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.



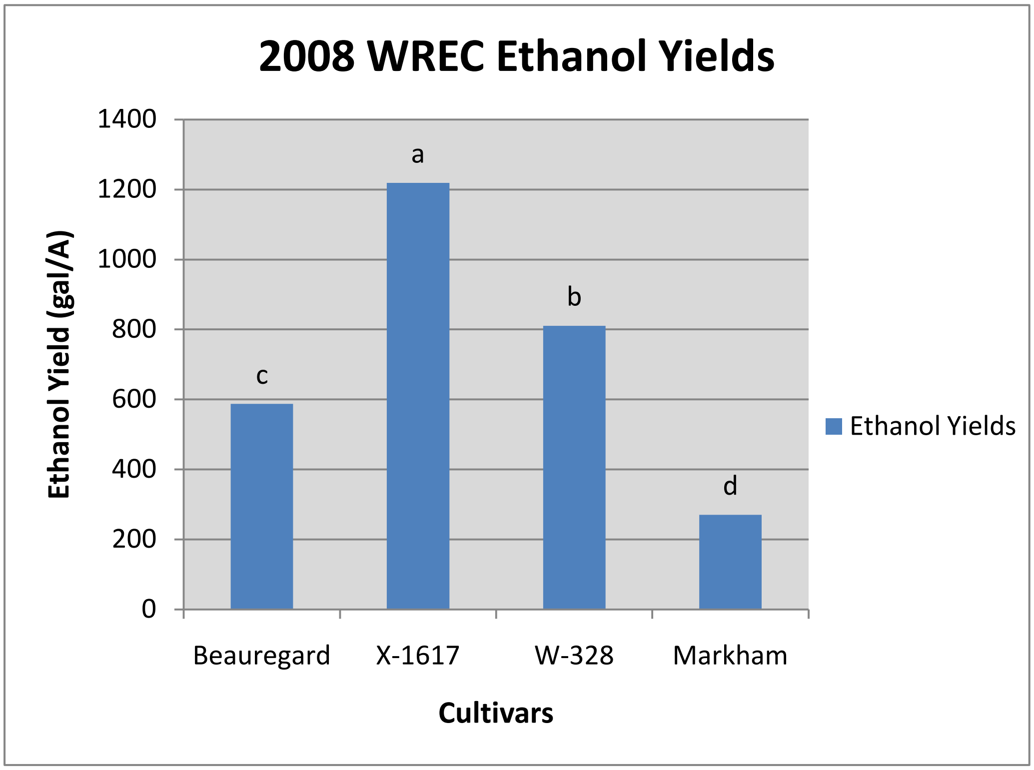
Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test (P≤0.05).

Figure 3. Sweetpotato yields for the spring 2008 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.



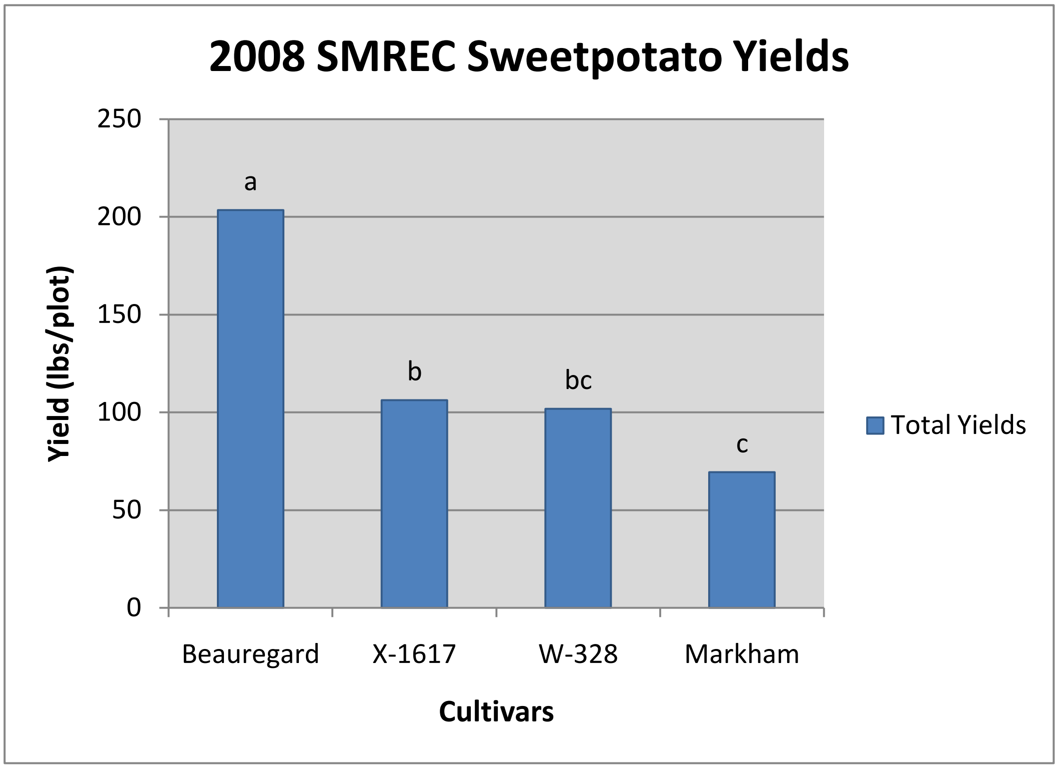
Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test (P≤0.05).

Figure 4. Sweetpotato ethanol yields for the spring 2008 cultivar study conducted at the Wiregrass Research and Extension Center, Headland, AL.



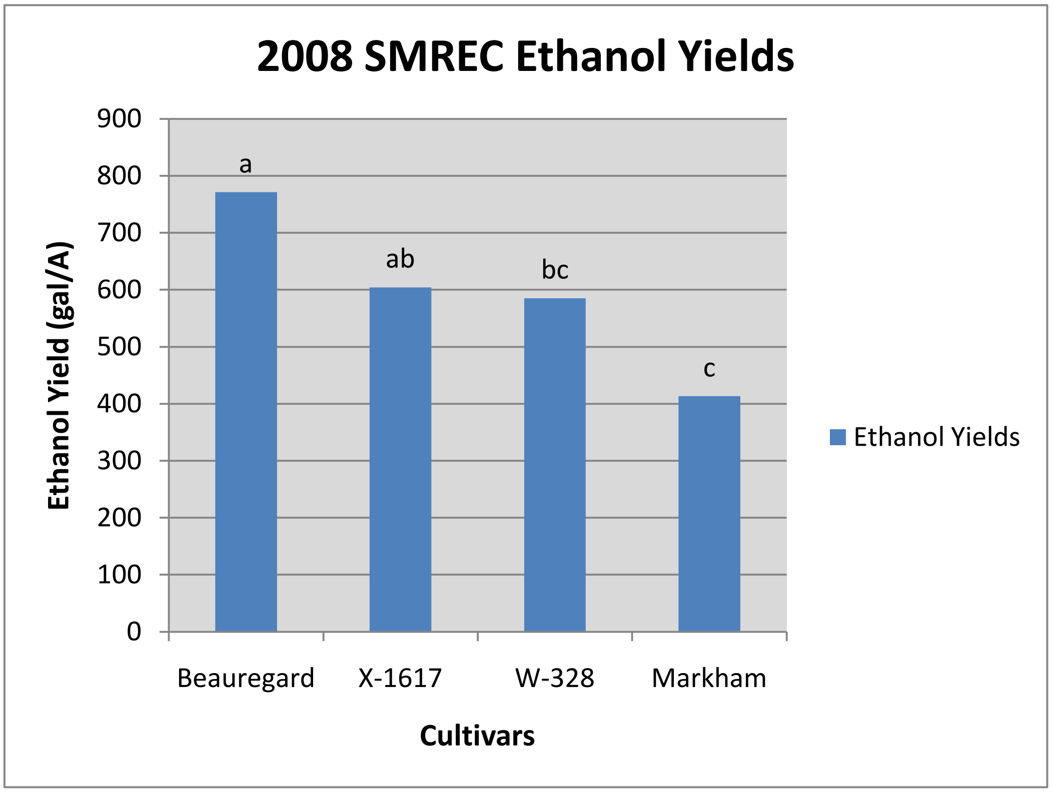
Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 5. Sweetpotato yields for the spring 2008 cultivar study conducted at the Sand Mountain Research and Extension Center, Crossville, AL.



Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 6. Sweetpotato ethanol yields for the spring 2008 cultivar study conducted at the Sand Mountain Research and Extension Center, Crossville, AL.



Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

CHAPTER III

EVALUATION OF NITROGEN REQUIREMENTS OF SELECTED SWEETPOTATO CULTIVARS FOLLOWING A COVER CROP OF CRIMSON CLOVER

ABSTRACT. Field studies were conducted evaluating nitrogen requirements of selected sweetpotato (*Ipomea batatas* (L.) Lam.) cultivars following a cover crop of crimson clover (*Trifolium incarnatum* L.) Treatments included 0, 45, and 90 lbs./A N behind clover and a conventional bareground treatment receiving 90 lbs./A N. Data from these studies indicate conventional N rate (90 lbs./A N) can be reduced when sweetpotatoes are produced following a winter cover crop of crimson clover. Sweetpotato yields from the treatment receiving 45 lbs./A N were similar (2007) and greater (2008) than the conventional treatment. Dry matter was also higher in all fertilizer treatments following clover compared to the conventional rate. These results show that sweetpotatoes can be produced successfully with half (45 lbs./A N) the recommended rate of N fertilizer following a winter cover crop of crimson clover.

Introduction

Sweetpotato is a tender, warm-season vegetable that grows as a perennial in tropical and sub-tropical climates, and as an annual in temperate regions (Swaider and Ware, 2002). Sweetpotato, a member of the Convolvulaceae family, is native to Central and South Americas with the first recorded use in the U.S. in the early 1600's. Sweetpotatoes thrive under the hot conditions of the southern U.S. but can be grown as far north as southern Michigan (Splittstoesser, 1990). Cultivars vary in color from white to orange and even purple (Kays and Wang, 2002). Several differences are notable between white-fleshed and the familiar orange-fleshed sweetpotatoes grown throughout the southern U.S. In general, white-fleshed types tend to be higher in dry matter (25% to 40%), less sweet, larger in size, and are not considered a main food-source crop (O'Hair, 1990). Most industrial type sweetpotatoes are white-fleshed. Common sweetpotato cultivars grown in Alabama for human consumption include 'Beauregard', 'Hernandez', and 'Jewel'.

A well-drained soil is the most important cultural concern in sweetpotato production. Flooding can be a severe problem for sweetpotatoes in Atlantic and Gulf Coast states in the U.S. The most productive soils are sandy loam and silt loam soils underlaid by finer textured subsoils (Dainello, 2003). Soils with poor internal drainage and soils high in organic matter can produce rough or odd shaped sweetpotatoes that are damaged by scurf (Thompson et al., 2002). Fields are commonly avoided that have produced a crop of sweetpotatoes in the past two years, have high nematode populations, and that are grassy or highly eroded (Kemble et al., 2006). Before planting, soil tests are conducted to determine soil condition and fertilizer recommendations. The optimum pH for sweetpotatoes is 5.8 to 6.2 (Maynard and Hochmuth, 2007). Under average soil conditions, current fertilizer recommendations for sweetpotato production in Alabama are 80 to 90 lbs. of nitrogen (N), 150 to 160 lbs. of phosphorous (P_2O_5), and 60 to 80 lbs. of potash (K_2O) per acre (Kemble et al., 2006). Fertilizer is applied before bedding or at bedding for proper distribution throughout the bed, avoiding direct contact with newly planted slips to prevent burning of foliage (Thompson et al., 2002).

Although referred to as "seed", sweetpotatoes are propagated vegetatively from sprouts or slips. The choices of seed stock greatly influence the success of the sweetpotato crop and are usually selected from the previous year's crop. Seed stock used for slip production is generally true to type, free from disease or insect damage, and free of veins.

Before slip production begins, seed stock is commonly presprouted by placing seed stock in a controlled storage area such as a curing room where temperature, relative humidity, and ventilation are carefully controlled. Presprouting encourages more prolific sprouting of roots and can decrease production costs by decreasing the total amount of seed stock required (Motes and Criswell, 2007). After presprouting, seed stock is treated with a recommended fungicide dip to control surface infestations of black rot, scurf, and root rot organisms (Motes and Criswell, 2007).

Each bushel of seed stock will produce 1,000 to 1,500 slips in 10 to 15 square feet of bed area (Thompson et al., 2002). Slips are harvested when they have six to 10 leaves and a strong root system. When harvested, slips are cut one inch above the bed surface and trimmed to 10 to 12 inches (Thompson et al., 2002). Depending on the location, slips are set in the field from mid-spring to early summer. Prior to planting, a recommended preemergence herbicide program is employed to control various grass weeds that can infest a field. Chemical treatments for broadleaf weeds are not as effective, although there are some available. Sweetpotato transplants are set deep, with at least three nodes below ground level (Granberry et al., 2007). The most efficient method for planting large numbers of slips is with a mechanical transplanter. Typical transplanters plant four to six rows at a time but require excessive labor. Common spacing is 12 inches between plants and 36 to 42 inches between rows. Depending on spacing, 9,000 to 18,140 slips will be required per acre (Maynard and Hochmuth, 2007). Although not a requirement, a light irrigation of 0.50 to 0.75 inches per acre helps establish young slips (Kemble et al., 2006). Most sweetpotato cultivars are ready to harvest in 90 to 120 days (Thompson et al., 2002). Following harvest, sweetpotatoes are cured for seven to 10 days to minimize storage losses then kept in storage at temperatures between 13 and 15 ºC (55.4 to 59 °F) at 90% humidity (Kays and Wang, 2002). Most properly stored sweetpotatoes will keep sufficiently for four to seven months (Kemble et al., 2006).

Cover crops have become a viable option of any cropping system that seeks to be sustainable. Cover cropping is the practice of growing pure or mixed stands of annual, perennial, or biennial herbaceous plants to cover the soil of croplands for all or part of the year when the soil might otherwise be fallow (Stone, 2005). Before commercial synthetic fertilizers were available, vegetable producers used cover crops to replenish soil nutrients. Cover crops provide soil erosion protection, reduce nutrient leaching, and help with weed suppression and pest management (Dabney et al., 2001). Cover crops can also improve the quality and health of the soil by adding biomass and increasing soil organic matter (Beaulieu and Marsh, 2002). The use of legume cover crops as a green manure can be a means of reducing the amount of conventional N fertilizer needed in some cropping systems (Stute, 1995). A green manure is a crop used primarily as a soil amendment and a nutrient source for subsequent crops (Cherr et al., 2006). Crimson clover is the most commonly used and most desirable of the clovers grown for a cover crop. Crimson clover, also known as Italian clover, is an annual cool season legume in the Fabaceae family. The leaves are palmately tri-foliate and the heads are deep red and cylindrical in shape. Crimson clover matures and produces more N and dry matter earlier than most other clovers (Larson, 2004). Crimson clover can often provide more than 100 lbs. of N per acre. Green forage of crimson clover normally contains about 0.75 to 1% N while dry forage about 3 to 3.5% N (Ball and Lacefield, 2000). The maximum amount of N is accumulated when crimson cover is allowed to reach the late bloom stage prior to being killed or turned under. For best results, crimson clover is generally incorporated into the soil two to three weeks before the succeeding crop (Sattell et al., 1998). In a study conducted at Oregon State University, 'Common Dixie' crimson clover planted in mid-September accumulated a maximum of 157, minimum of 55, and average of 108 lbs. N/acre by mid-April over a five year replicated trial (Sattell et al., 1998). Crimson clover is commonly used as a green-manure crop in pecan and other orchard crops in the southeastern U.S.

Using cover crops as a green manure can often lower the amount of conventional N required in some cropping systems. With that in mind, the objective of this study was to evaluate nitrogen requirements of selected sweetpotato cultivars following a crimson clover cover crop.

Materials and Methods

Field studies were conducted in the spring of 2007 (June 15th) and 2008 (April 22nd) at the Wiregrass Research and Extension Center (WREC) located in Headland, AL to evaluate the influence of a crimson clover cover crop on N requirements of sweetpotatoes. Soil type was a Dothan sandy loam (fine-loamy, kaolinitic, thermic

Plinthic Kandiudults) (USDA series description). In the 2007 study 'Beauregard' was used while 'X-1617' was chosen for the 2008 study. Slips for 'X-1617' were produced in slip beds located at the WREC according to standard slip production practices. 'Beauregard' slips were supplied by the North Alabama Horticulture Research Center (NAHRC) located in Cullman, AL. In both studies, the soil was prepared and formed into 16 plots consisting of two 25' rows spaced 3' apart. Plots were spaced 10' apart with 25' alleys. A total of four treatments consisting of four replications were arranged in a RCBD. Treatments consisted of three one-time applications of 0, 45, and 90 lbs./A following crimson clover and also a conventional bareground treatment which consisted of a one-time application of 90 lbs./A N (control). The crimson clover was established in 2004 at a seeding rate of 25lbs./A and allowed to reseed every year. Accumulated foliage was allowed to seed then tilled in three weeks prior to planting of sweetpotatoes. Two days before planting, a preemergence herbicide was applied (Valor, Valent Biosciences, Libertyville, IL) at labeled rates to control annual broadleaf weeds. Fifty slips per plot were planted on a 12" spacing using a mechanical transplanter. Immediately after planting an additional pre-emergent herbicide (Command 3ME, FMC Corporation, Philadelphia, PA) was applied at labeled rates to control annual grasses and broadleaf weeds. Sweetpotatoes were watered by center-pivot irrigation throughout the course of this study during periods of drought. Sweetpotatoes were harvested in November using a three-point chain digger then bagged and weighed in the field according to plot.

Data were analyzed with SAS's Proc GLM procedure for ANOVA and Waller-Duncan's K-ratio t Test was used for means separation (SAS Institute, Cary, NC).

Results and Discussion

In 2007, no differences were observed in yields of ‘Beauregard’ among the treatments examined (Table 7). Yields were respectable in this 158 day study, ranging from 29,454 lbs./A for the conventional treatment to 36,969 lbs./A for the 0 lbs. N/A treatment grown behind a crimson clover cover crop.

In 2008 the nitrogen study at the WREC was repeated. The cultivar was changed from ‘Beauregard’ to the high dry matter industrial type ‘X-1617’. Analysis showed yields were affected by the treatments ($P<0.0009$) (Table 8). All three treatments grown following the crimson clover cover crop were similar and had higher yields compared to the conventional treatment (no cover crop) (Table 8; Figure 8). Dry matter of the storage roots was measured in 2008 and was affected by treatment ($P<0.0024$) (Table 8). Treatments receiving 45 and 90 lbs./A N following a crimson clover cover crop were similar (41.9 % and 42.1% dry matter respectively) and higher than the treatments receiving 0 lbs./A N behind crimson clover (37.4% dry matter) and the conventional treatment (37.7 % dry matter).

Data from these two studies indicate conventional N rate (90 lbs./A N) can be decreased by 50% when sweetpotatoes are grown following a winter crimson clover cover crop without a reduction in sweetpotato yield. Sweetpotato yields from the 45 lbs./A N treatment behind crimson clover were similar (2007) and greater (2008) than the conventional treatment. Dry matter was also higher for all treatments following the crimson cover clover crop in the 2008 study compared to the conventional rate.

When compared to conventional sweetpotato production (no cover crop), a crimson clover cover crop can reduce conventional N fertilizer needs and costs significantly. Crimson clover also increases soil organic matter, while reducing weed pressure and erosion. Crimson clover prices vary, but a 50 pound bag can be bought for $80 (Outside Pride, Salem, Oregon) which relates to $40/A to establish a stand of crimson clover at a seeding rate of 25lbs/A. At the time of this research ammonium nitrate (NH_4NO_3) was $440/ton (Piedmont Fertilizer, Opelika, AL) which equates to $42.90/A at the recommended fertilization rate of 90 lbs. N/A. While the cost of establishing crimson clover is $40/A, it would immediately reduce the N fertilization requirements by 50% and reduce N fertilization costs by 50% thereafter if the crimson clover was allowed to naturally reseed. Furthermore, yields were higher (2008) in all treatments following crimson clover compared to the conventional treatment.

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Table 7. Sweetpotato yields for the spring 2007 ‘Beauregard’ nitrogen study conducted at the Wiregrass Research and Extension Center, Headland, AL.

Treatment	Yield (lbs/plot)	Yield (lbs/A)[Z]
90 lbs N/A clover	116.83a[Y]	33,926a
45 lbs N/A clover	113.85a	33,062a
0 lbs N/A clover	127.23a	36,969a
90 lbs N/A conventional	101.43a	29,454a
Observed P-value (<0.4286)		

[Z]Yield (lbs/A) = lbs/plot * 290.4
[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Table 8. Sweetpotato yields for the spring 2008 ‘X-1617’ nitrogen study conducted at the Wiregrass Research and Extension Center, Headland, AL.

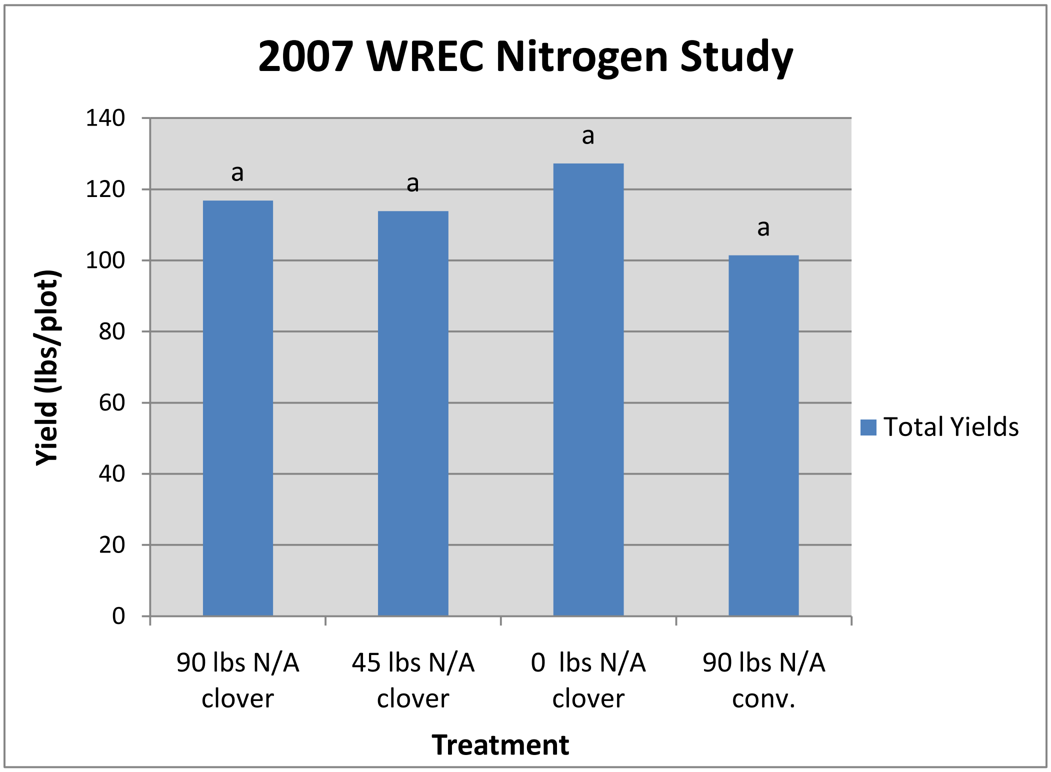
Treatment	Yield (lbs/plot)	Dry Matter (%)	Yield (lbs/A)[Z]
90 lbs N/A clover	220.45a[Y]	42.1a	64,018a
45 lbs N/A clover	233.93a	41.9a	68,955a
0 lbs N/A clover	215.65a	37.4b	62,624a
90 lbs N/A conventional	128.93b	37.7b	37,439b

Observed P-value (<0.0009) for Yield
Observed P-value (<0.0024) for Dry Matter

[Z]Yield (lbs/A) = lbs/plot * 290.4

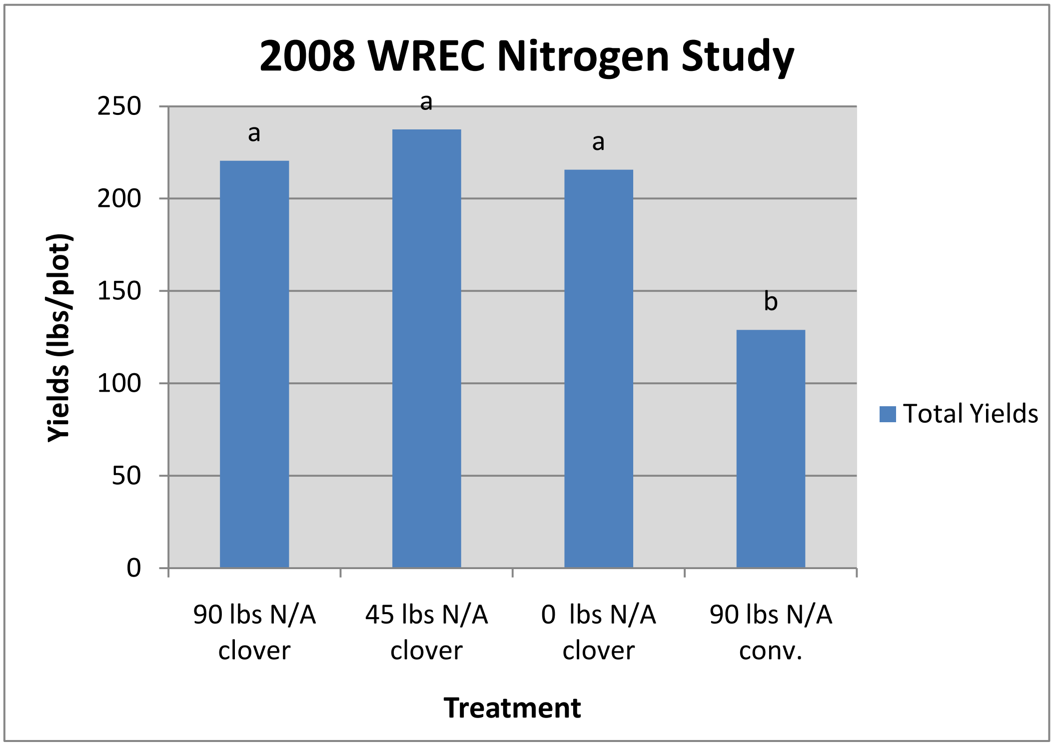
[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 7. Sweetpotato yields for the spring 2007 'Beauregard' nitrogen study conducted at the Wiregrass Research and Extension Center, Headland, AL.



Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 8. Sweetpotato yields for the spring 2008 'X-1617' nitrogen study conducted at the Wiregrass Research and Extension Center, Headland, AL.



Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

CHAPTER IV

EVALUATION OF IN-GROUND STORAGE OF SELECTED SWEETPOTATO CULTIVARS

ABSTRACT. Industrial sweetpotatoes (*Ipomea batatas* (L.) Lam.) were evaluated to determine in-ground storage viability for prolonging harvest periods and reducing storage costs in central Alabama. A field study with 'X-1617' evaluated the following harvest periods: October, November, December, and January. Data collected included sweetpotato yield, dry matter, and soil temperature. As soil temperature decreased, both sweetpotato yield and dry matter decreased. Reduced sweetpotato yields were observed in the December and January harvests while a reduction in storage root dry matter was observed in the November, December, and January harvest periods.

Introduction

Sweetpotato is a tender, warm-season vegetable that grows as a perennial in tropical and sub-tropical climates, and as an annual in temperate regions (Swaider and Ware, 2002). Sweetpotato, a member of the Convolvulaceae family, is native to Central and South Americas with the first recorded use in the U.S. in the early 1600's. Sweetpotatoes thrive under the hot conditions of the southern U.S. but can be grown as far north as southern Michigan (Splittstoesser, 1990). Cultivars vary in color from white to orange and even purple (Kays and Wang, 2002). Several differences are notable between white-fleshed and the familiar orange-fleshed sweetpotatoes grown throughout the southern U.S. In general, white-fleshed types tend to be higher in dry matter (25% to 40%), less sweet, larger in size, and are not considered a main food-source crop (O'Hair, 1990). Most industrial sweetpotatoes are white-fleshed types. Common sweetpotato cultivars grown in Alabama for human consumption include 'Beauregard', 'Hernandez', and 'Jewel'.

A well-drained soil is the most important cultural concern in sweetpotato production. Flooding can be a severe problem for sweetpotatoes in Atlantic and Gulf Coast states in the U.S. The most productive soils are sandy loam and silt loam soils underlaid by finer textured subsoils (Dainello, 2003). Soils with poor internal drainage and soils high in organic matter can produce rough or odd shaped sweetpotatoes that are damaged by scurf (Thompson et al., 2002). Before planting, soil tests are conducted to determine soil condition and fertilizer recommendations. The optimum pH for sweetpotatoes is 5.8 to 6.2 (Maynard and Hochmuth, 2007). Under average soil conditions, current fertilizer recommendations for sweetpotato production in Alabama is 80 to 90 lbs. of nitrogen (N), 150 to 160 lbs. of phosphorous (P_2O_5), and 60 to 80 lbs. of potash (K_2O) per acre (Kemble et al., 2006). Fertilizer is applied before bedding or at bedding for proper distribution throughout the bed, avoiding direct contact with newly planted slips to prevent burning of foliage (Thompson et al., 2002).

Although referred to as "seed", sweetpotatoes are propagated vegetatively from sprouts or slips. The choices of seed stock greatly influence the success of the sweetpotato crop and are usually selected from the previous year's crop. Seed stock used for slip production is generally true to type, free from disease, insect damage and veins.

Before slip production begins, seed stock is commonly presprouted by placing seed stock in a controlled storage area such as a curing room where temperature, relative humidity, and ventilation are carefully controlled. Presprouting encourages more prolific sprouting of roots and can decrease production costs by decreasing the total amount of seed stock required (Motes and Criswell, 2007). After presprouting, seed stock is treated with a recommended fungicide dip to control surface infestations of black rot, scurf, and root rot organisms and then placed into beds (Motes and Criswell, 2007).

Each bushel of seed stock will produce 1,000 to 1,500 slips in 10 to 15 square feet of bed area (Thompson et al., 2002). Slips are harvested when they have six to 10 leaves and a strong root system and are typically cut one inch above the bed surface and trimmed to 10 to 12 inches (Thompson et al., 2002).

Depending on the location, slips are set in the field from mid-spring to early summer. Prior to planting, a recommended pre-emergent herbicide program is employed to control various grass weeds that can infest a field. Sweetpotato transplants are set deep, with at least three nodes below ground level (Granberry et al., 2007). The most efficient method for planting large numbers of slips is with a mechanical transplanter. Typical transplanters plant four to six rows at a time but require excessive labor. Common spacing is 12 inches between plants and 36 to 42 inches between rows. Depending on spacing, 9,000 to 18,140 slips will be required per acre (Maynard and Hochmuth, 2007). Most sweetpotato cultivars are ready to harvest in 90 to 120 days (Thompson et al., 2002). Following harvest, sweetpotatoes are cured for seven to 10 days to minimize storage losses then stored at temperatures between 13 and 15 ºC (55.4 to 59 °F) at 90% humidity (Kays and Wang, 2002). Most properly stored sweetpotatoes will keep successfully for four to seven months (Kemble et al., 2006). In many countries sweetpotatoes are stored in-ground and harvested as needed. In Uganda, sweetpotato farmers practice in-ground storage combined with piecemeal harvesting. The overall aim of this practice is to maintain a supply of roots for the longest possible period (Smit, 1997). In China, sweetpotatoes are stored in tunnels or holes dug in the ground (Woofle, 1992).

To reduce storage costs and extend the harvesting period, the objective of this study was to evaluate in-ground storage of industrial sweetpotatoes.

Materials and Methods

A field study evaluating in-ground storage of a high-yielding industrial sweetpotato cultivar was conducted in the spring of 2008 (June 17th) at the Old Agronomy Farm (OAF) at Auburn University, AL. Soil type was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic type Kandiudults) (USDA series description). 'X-1617' sweetpotatoes were grown in heated slip beds located at Auburn University. The soil was prepared and formed into 16 plots consisting of two 25' rows spaced 3' apart. Plots were spaced 10' apart with 25' alleys. Treatments consisted of the following harvest periods: October, November, December, and January. Treatments were arranged in a RCBD with four replications. Two days before planting a preemergence herbicide was applied (Valor, Valent Biosciences, Libertyville, IL) at labeled rates to control annual broadleaf weeds. A total of 50 slips per plot were planted on a 12" spacing. Immediately after planting an additional preemergence herbicide (Command 3ME, FMC Corporation, Philadelphia, PA) was applied at labeled rates to control annual grasses and broadleaf weeds. All P_2O_5, K_2O and half of recommended N fertilizer was applied at planting based on soil test recommendations. The remainder of N fertilizer was applied once vines began to run. Slips were irrigated once immediately after planting, but received no additional irrigation. The sweetpotatoes were harvested by hand at the end of each month then bagged and weighed in the field according to plot. Soil temperatures were also measured at the depth of storage root formation (6 inches within the row of developing sweetpotatoes) using HOBO® Temp Pro (Onset Computer Corporation, Bourne, Mass.) data loggers. These probes recorded temperature measurements from 1 Oct. through 31 Jan. 2008 every 6 hours throughout the day. The temperature probes were inserted by hand into the center of the middle rows of each three-row plot. Temperature measurements were taken in two of the four replications of the January harvest (replications two and four). After harvesting, samples of each treatment were analyzed for moisture content.

Data were analyzed with SAS's Proc GLM procedure for ANOVA and Waller-Duncan's K-ratio T Test was used for means separation (SAS Institute, Cary, NC).

Results and Discussion

Analysis indicated sweetpotato yield and dry matter were affected by harvest date ($P<0.0001$) (Table 9). Sweetpotato yields and dry matter decreased as soil temperature decreased. Sweetpotato yields for October 31st and November 28th harvests were the highest and similar while yields were reduced significantly in the December 31st and January 30th harvests (Table 9, Figure 9). A reduction in dry matter was seen in the November 28th, December 31st, and January 30th harvests.

Average soil temperatures were different among harvest periods ($P<0.0001$) (Table 10). Soil temperatures decreased from October thru January harvests (Figure 10).

Results from this study indicate in-ground storage of industrial sweetpotatoes in Alabama appears to be promising. However, sweetpotatoes were damaged significantly once soil temperatures fell below 12.7°C (55°F). More research is needed to validate in-ground storage guidelines. Future studies are planned to evaluate in-ground storage of sweetpotatoes in south Alabama where winter temperatures are milder and in-ground storage may be more feasible.

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Table 9. Sweetpotato yields for the spring 2008 storage study conducted at the Old Agronomy Farm, Auburn University, AL.

Treatment	Yield (lbs/plot)	Dry Matter (%)	Yield (lbs/A)[Z]
October (160 days)	170.31a[Y]	38.4a	49,458a
November (191 days)	162.55a	33.0b	47,204a
December (228 days)	83.18b	29.5c	24,155b
January (258 days)	40.99c	27.7c	11,903c
Observed P-value (<0.0001)			

[Z]Yield (lbs/A) = lbs/plot * 290.4

[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

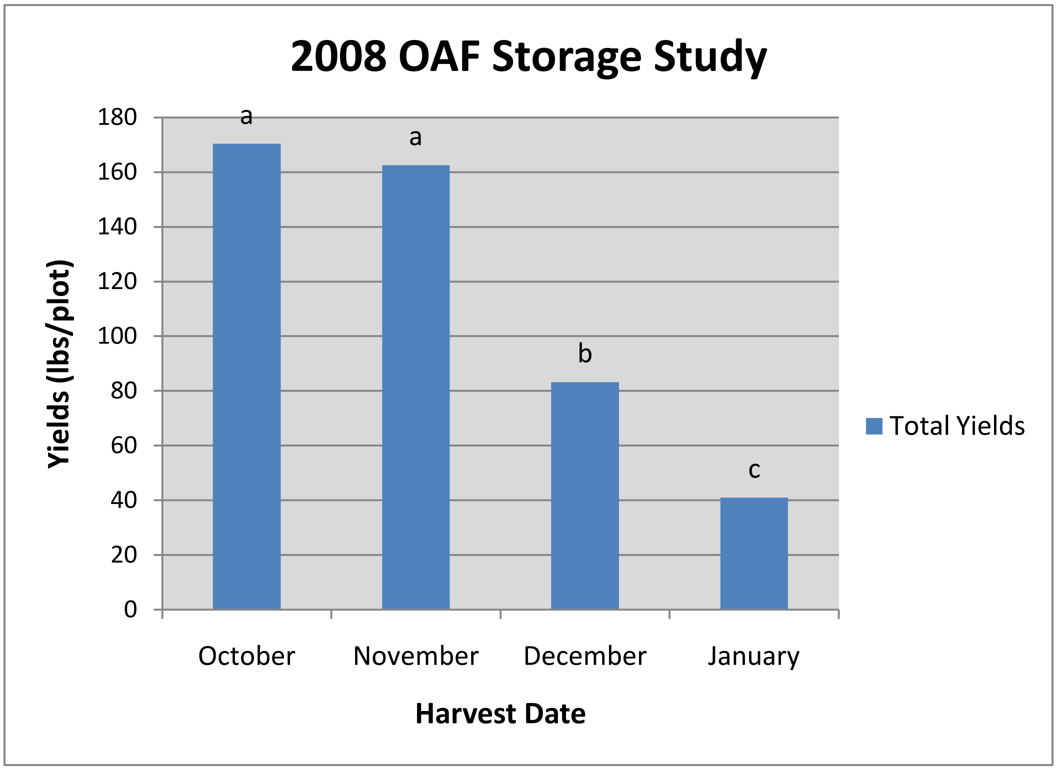
Table 10. Average monthly soil temperatures recorded at 6:00 a.m. for spring 2008 storage study conducted at the Old Agronomy Farm, Auburn University, AL.

Treatment	Soil Temperature (°C)[Z]
October 31st (160 days)	18a[Y]
November 28th (191 days)	12.16b
December 31st (228 days)	11.66bc
January 30th (258 days)	8.71c
Observed P-value (<0.0001)	

[Z]Temperature recorded at 6:00 a.m. CST by Hobo® Pro temperature data loggers

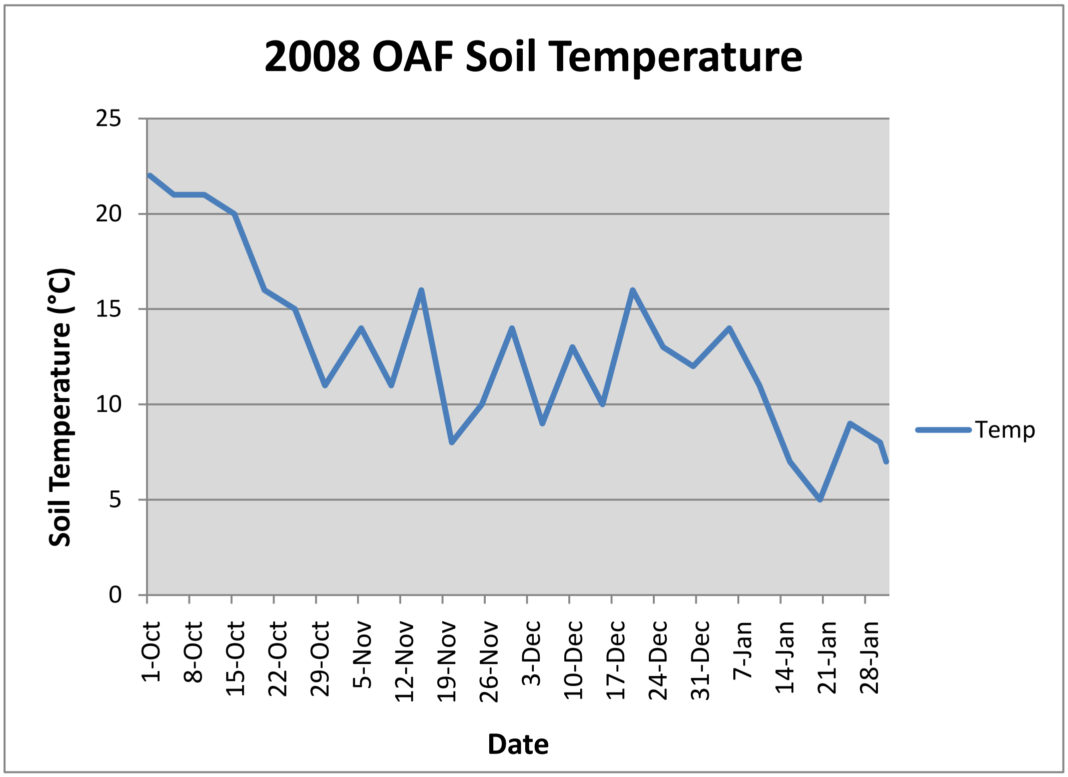
[Y]Means followed by the same letter are not significantly different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 9. Sweetpotato yields for the spring 2008 storage study conducted at the Old Agronomy Farm, Auburn University, AL.



Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).

Figure 10. Recorded soil temperatures for the spring 2008 storage study conducted at the Old Agronomy Farm, Auburn University, AL.



Temperature recorded at 6:00 a.m. CST by Hobo® Pro Series temperature data loggers.

CHAPTER V

FINAL DISCUSSION

Today the U.S. economy is dependent on technologies that rely heavily on fossil energy to produce power, chemicals, fuels, and materials. Biofuels such as ethanol present a promising renewable energy opportunity that could provide an alternative to the use of fossil fuel resources (Pastor et al., 2003). While research and development of lignocellulosic conversion processes is essential to U.S. progress towards replacing fossil fuels with alternative energy, emphasis can still be placed on finding alternative and abundant starch and sugar sources where conversion technologies already exist and will not interfere with food and feed production (Duvernay, 2008). Sweetpotato (*Ipomea batatas* (L.) Lam.) is one of the most important starch-producing crops grown worldwide. Due to its ease of cultivation, low fertilizer inputs, high adaptability, and high starch content, sweetpotatoes may offer an alternative feedstock for starch-based ethanol production (Santa-Maria, 2009).

Prior to this research, only one other study had been conducted on producing industrial sweetpotatoes for ethanol in Alabama. That study was being conducted at the same time as the one discussed here. Our studies indicated that the industrial sweetpotatoes ‘X-1617’ and ‘W-328’are capable of producing large amounts of biomass without the need for costly inputs. Our studies also indicate that these industrial cultivars continue to produce biomass throughout the entire cropping season. In 2008, sweetpotatoes were planted earlier and left in production for 40 days longer than the study conducted the previous year. 'X-1617' and 'W-328' yielded more when planted earlier in the season and left in production for a longer period of time while there was little difference seen for 'Beauregard'.

Nitrogen studies using both 'Beauregard' and 'X-1617' sweetpotatoes indicated that the recommended N rate of 90 lbs./A could be reduced by 50% with no differences in storage root yield or dry matter when produced following a winter cover crop of crimson clover. These results are very positive for growers in regards to reducing fertilizer inputs and improving soil tilth. Our in-ground storage study showed sweetpotatoes could possibly be stored in-ground as an alternative to storage houses. However, once temperatures drop below 12.7°C (55°F) sweetpotatoes are damaged significantly. Future storage studies performed in areas with milder winters such as south Alabama would be useful in determining whether in-ground storage of industrial sweetpotatoes could be a viable option here in Alabama. Storing sweetpotatoes in-ground would also be very important to growers because of ease of storage, space, and profit potential.

In conclusion, production of industrial sweetpotatoes for ethanol production in Alabama appears very promising based on the results from these experiments. Industrial sweetpotato cultivars can be produced in Alabama without irrigation and with reduced rates of conventional fertilizers. While the sweetpotato production system needs more research in order to further lower production costs and make industrial sweetpotatoes economically competitive with other bioenergy crops, the studies performed over the last two years provide great promise for growers looking for a bioenergy crop for Alabama. More research is needed to develop a totally mechanized or alternative system for planting sweetpotato slips as well as continuing to evaluate in-ground storage of sweetpotatoes.

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APPENDIX A

EVALUATION OF ALTERNATIVE SUBSTRATES FOR PRODUCTION OF SWEETPOTATOES

Sweetpotato (*Ipomea batatas* (L.) Lam.) is a low-input crop that is grown worldwide on a wide range of soils that can produce satisfactory yields on marginal lands. For sweetpotato to become a viable biofuel crop in Alabama, a large amount of land would be needed for production of the crop without taking away from what is needed for main food-source crops. Alternative sweetpotato production methods as well as production on non-croplands such as old landfills may be needed to meet the demand needed for ethanol production. Because of the potential for sweetpotato to be grown on marginal lands, alternative substrates were evaluated for production of sweetpotato.

On April 16th, 2007 two 'Beauregard' sweetpotato slips were potted into 10 gallon pots in the following substrates: mineral soil, 4:1 mineral soil:composted poultry litter (CPL) (v:v), cotton gin waste, 1:1 CPL:pine bark (v:v), 6:1 pine bark:sand, composted household garbage (WastAway Sciences Inc., McMinnville, TN) clean chip residual, 1:1 sand:small HydRocks® (Big River Industries, Alpharetta, GA) (v:v), and 1:1 sand:large HydRocks® (v:v) (Table A1). A total of six replications per treatment were used. Sweetpotato slips were thinned to a single slip once established. Each substrate was pre-plant incorporated with 2.5 pounds per cubic yard of N from a controlled release fertilizer (18-6-12 Poly-on, Agrium Advanced Technologies, Sylacauga, AL), 5 pounds per cubic yard of dolomitic limestone and l.5 pounds per cubic yard of micromax (The Scotts Co). Pots were randomly placed onto a nursery pad and were watered daily under standard overhead irrigation at 0.75 inches per day. The water regimen was based on maintenance of suitable moisture for the 6:1 pinebark:sand substrate.

On November 8th, 2007 sweetpotatoes were harvested by hand with root fresh weight recorded as well as total root number per container. All data were analyzed using the GLM procedure with mean separation by Waller-Duncan K-ratio T test (SAS version 9.1, SAS Institute, Cary N.C.).

Sweetpotato fresh weight was different by treatment ($P<0.0001$) (Table A1). Plants grown in 1:1 CPL:pine bark (v:v), composted garbage, clean chip residual, 1:1 sand:small HydRocks® (v:v), and 1:1 sand:large HydRocks® (v:v) were all similar in root fresh weight. Both treatments utilizing mineral soil performed poorly due to excessive water and drainage issues. Future studies are needed to compare these substrates to traditional field grown sweetpotato yields.

Differences were observed across treatments in number of sweetpotato roots ($P<0.0003$) (Table A1). Plants grown in 1:1 CPL:pine bark (v:v), garbage compost, clean chip residual, 1:1 sand:small HydRocks® (v:v), and cotton gin waste were all similar. As noted earlier, treatments using mineral soil performed poorly due to excessive water for mineral soil in a container.

Although a comparison could not be made to 100% mineral soil (damage), all treatments with the exception of mineral soil and 3:1 mineral soil:CPL performed well in terms of sweetpotato fresh weight. Future research is warranted to determine if sweetpotatoes can be successfully grown in alternative substrates in field plots or permaculture beds.

Table A1. Yield evaluation of different container substrates in the production of 'Beauregard' sweetpotato.

Treatment	Count (sweetpotatoes/pot)	Yield (lbs/pot)
100% Cotton Gin Waste	17	10.70
1:1 Composted Poultry Litter: Sand (v:v)	17	14.42
6:1 Pine Bark: Sand (v:v)	13	14.58
100% Garbage Compost	11	13.13
100% Clean Chip Residual	17	13.26
1:1 Sand: Large Hydrocks® (v:v)	10	11.09
1:1 Sand: Small Hydrocks® (v:v)	14	13.73
Observed P-value (<0.0001)		

Means followed by the same letter are not different according to Waller-Duncan K-ratio T Test ($P \leq 0.05$).