THE SUSTAINABILITY OF TROPICAL MAIZE AS AN ALTERNATIVE BIOFUEL OR SILAGE CROP

BY

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THESIS

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ABSTRACT

With increasing world population, the U.S. Department of Energy initiated the Energy Independence and Security Act (EISA) requiring by 2030 the replacement of 30% of petroleum based fuel sources with biofuel (USDA 2010). Tropical maize (*Zea mays* L.) has potential as a new biofuel crop for the Midwestern US. It is a temperate by tropical (or tropical by tropical) hybrid that retains the photoperiod sensitivity of tropical materials when grown in temperate regions, resulting in high biomass, but with delayed flowering that reduces or eliminates grain production. The reduced grain production results in accumulation of sucrose in the stalk and a lower nitrogen fertilizer requirement. Our objective was to evaluate the impact of sustainable practices such as conservation tillage, cover crops, and reduced nitrogen fertilizer application on tropical maize as a biofuel, biomass, or animal feed crop. Tropical maize hybrids have been characterized as: 1) dual purpose, producing high biomass levels with high quality grain that can be harvested for the grain and the stover used in a bale-burning furnace for thermal energy, or that can be ensiled for use as animal feed; and 2) high sugar, producing high biomass and high stalk sugar accumulation that can be used for ethanol production. The experiment was conducted in Champaign, IL in 2014 and 2015. The two hybrid types were planted into tilled strips evaluated under three nitrogen rates of 0, 67 and 202 kg N ha^{-1}. Two annual cover crops, annual ryegrass and pennycress, were compared to a perennial ground cover, creeping bentgrass, and a no-cover control. Annual cover crops produced tropical maize biomass yields similar to the no-cover control regardless of hybrid. Animal performance was similar when fed tropical maize grown at a lower rate of nitrogen compared to conventional field corn silage. Results show that a management system that optimizes the environmental sustainability of tropical maize can be used while maintaining a competitive yield.

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LITERATURE REVIEW

Evolution and Utilities of Maize

Maize (*Zea mays* L.) was domesticated over 9,000 years ago in southern Mexico (Goodman, 1999; Matsuoka et al., 2002; Van Heerwaarden et al., 2011). The ancestor of maize, teosinte (*Zea mays* L. subsp. *parviglumis*), with origins in the subequatorial latitudes was exposed to day length and precipitation that cycled annually, developing photoperiod sensitivity that aligned the reproductive phases of the crop (Mungoma and Pollak, 1991; Ribaut et al., 1996; Campos et al., 2006). Maize adapted to longer day lengths as it moved into temperate regions, which resulted in the genetic differentiation between temperate and tropical maize germplasm, causing reduced photoperiod sensitivity of temperate material (Goodman, 1988; Gouesnard et al., 2002). Tropical germplasm grown in a temperate zone with dark periods of less than 12 hours exhibits asynchrony of flowering from an increased anthesis-silking interval, reducing or eliminating ear growth or grain development (Mungoma and Pollak, 1991; Edmeades et al.,1999). This photoperiod response of tropical material grown in temperate regions also includes increased biomass accumulation compared to temperate germplasm resulting from increased plant height and greater leaf number (Goodman, 1999; Gouesnard et al., 2002). As a result of reduced or eliminated grain formation, there is a substantial accumulation of extractable stalk sugars (Clark, 1913; Sayre et al., 1931; Singleton, 1948; Marten and Westerberg, 1972; Widstrom et al., 1984).

In the early domestication of corn, it was not originally used for its grain production but for the sugars accumulated in the stalk (Iltis, 2000; Smalley and Blake, 2003). Alcohol production from the sugars in the stalks of corn promoted its rapid spread and use. Sugarcane (*Saccharum officinarum*) had wide-spread use as a sugar crop prior to and after the discovery of the New World (Mintz, 1985). With no indigenous source of sugar, and inhospitable growing conditions for sugarcane, the maize and teosinte species began to be used in the Americas. Sugarcane and maize are in the grass family of Poaceae and both produce sweet juice in the stalk that continue to be used for sugar extraction to produce syrup and alcohols (Smalley and Blake, 2003). Only through a mutation found by hunter-gathers, the 2 rowed, 5- to 12-grained ear of teosinte was exposed from under the hard fruit case and collected and planted, initiating the transition of maize from a sugar crop to a grain crop (Iltis, 2000). By 1866, when recording began in the United States, 30 million acres (12 million ha) of corn for grain production were harvested, with current planted acreage reaching over 90 million (36 million ha) (USDA NASS, 2015). Currently, the U.S. corn industry converts 35 to 40% of the total grain yield into ethanol (alcohol) annually as a fuel source (USDA, 2015).

Another corn plant component used for feed and fuel is the stover, or leaf and stalk biomass. When corn stover is tallied across the U.S. Corn Belt, it offers a large total tonnage of recoverable crop residue-biomass. Corn stover is expected to provide about 25% of the total advanced biofuels supply (USDA, 2010). The Billion-Ton study conducted by the U.S. Department of Energy found that in 2011 there were 85-101 million dry metric tons of crop residue that could be used for ethanol production and projections of 290 million dry metric tons by 2030. Seventy-five percent of the crop residue total came from corn stover and the remainder from wheat straw and other small grain crops in 2011, with a projected increase to 85 percent by 2030. The predicted increase in crop residue dry tonnage is derived from increased yields and adoption of conservation tillage systems (US DOE, 2011). In the U.S., energy supply and sustainable use is a national priority. Driving this focus on renewable fuels is the need to reduce reliance on foreign oil, create clean energy jobs, increase overall energy efficiency and address climate change. Biomass energy provides an important source of renewable and sustainable energy.

The earliest automobiles, such as Henry Ford's Model T, were designed to be flexible in using fuel sources of alcohol (e.g. ethanol), gasoline, or a mixture of the two similar to the current flex-fuel cars of today (Solomon et al., 2007). Ethanol can be produced from fermentable sugars, starch-containing material (grains), and lignocellulosic biomass. Sugar-containing feedstocks, such as sugarcane in tropical environments, and sugar beets in European countries, are the most utilized for ethanol production in those given regions (Cardona and Sanchez, 2007). Other sugar-containing feedstocks are sweet sorghum and tropical maize, however, they can also provide starch and lignocellulosic material (White et al., 2011). Unlike the conversion of starch and lignocellulosic material, stalk sugars require less processing and less energy input. Only yeast is necessary to convert the disaccharides in the stalk juice into ethanol through fermentation (Sanchez and Cardona, 2008). Ethanol produced from starch is derived from corn, wheat (Triticum spp.), or cassava (*Manihot esculenta*, a tuber grown in tropical climates) depending on the region. Starch must first be converted into glucose, which subsequently is fermented by yeast into ethanol (Bothast and Schlicher, 2005). Lignocellulose from biomass material requires the most resources for conversion to ethanol, necessitating a pretreatment to disintegrate the complex structure of lignocellulose, comprised of lignin, hemicellulose, and cellulose. These various lignocellulosic components degrade at varying rates and eventually release sugars that can be converted to ethanol (Lynd et al., 1999).

In addition to transportation fuel, above-ground maize biomass can also be used to fuel ruminant animals. The use of maize as a silage crop first began in Hungary around 1860, shortly followed by Germany. Silage production in America began after a French book on making silage was translated into English in 1877, which further increased the production of maize in America (Mannetje, 2005). Currently, the U.S. has the highest acreage of corn silage in the world (Lauer et al., 2001). Silage is created from plant material that is harvested and ensiled for use as a feed source for ruminant animals, which are animals with a compartmentalized stomach that includes microbial fermentation located primarily in the rumen (Chalmers and Synge, 1954). Ensiling of the chopped forage material occurs in an anaerobic environment and results in the acidification of the plant material to preserve it for use by lactic acid bacteria (Mannetje, 2005). High protein concentration and digestibility (for high energy concentration) and low fiber (increasing intake potential) are desirable qualities within corn silage hybrids (Carter et al., 1991).

Tropical Maize

Tropical maize (*Zea mays L.*) has potential as a new biofuel and silage crop for the Midwestern U.S. It is a corn hybrid (made by crossing inbreds of tropical by tropical or tropical by temperate germplasm) that is adapted to tropical climates, causing photoperiod sensitivity when grown in temperate regions. The photoperiod sensitive trait results in delayed flowering, reduced grain production and a prolonged vegetative state triggered by the short-night environment of Midwestern latitudes (White et al., 2011). Reduced grain production results in the accumulation of sucrose in the stalk, and a reduced nitrogen requirement. Tropical maize contains the potential to extract sugar-containing juice from its stalks, starch from the grain that is produced, and its remaining biomass can be used as an important source of lignocellulosic biomass. Compared to conventional field corn, tropical maize doubles the amount of total biomass partitioned to the stalk when no nitrogen fertilizer is applied. Even when grain development occurs, tropical maize partitions a greater amount of biomass to the stalk and accumulates more sugar in the stalk than convention field corn (White et al., 2012).

When grown without nitrogen fertilizer, tropical maize can produce large amounts of biomass, 20-25 Mg ha^{-1} dry weight, and accumulate high levels of sugar; creating a biofuel feedstock for immediate use of the simple sugars and secondary use for cellulosic fermentations (White et al., 2012). Chen et al., (2013) analyzed tropical maize stalk syrup and determined it to be a competitive alternative biofuel feedstock, achieving 90.3-92.2% of theoretical ethanol yield. The theoretical ethanol yield of tropical maize from all plant components was 9119 liters ha^{-1} when produced with 202 kg N ha^{-1} and 6178 liters ha^{-1} when produced without nitrogen fertilizer. Potential ethanol yield of tropical maize is comparable to conventional corn hybrids when all plant components (sugar, starch, lignocellulosic biomass) are utilized (White et al., 2012). Utilizing all plant parts of select hybrids, tropical maize produced 25% more ethanol than conventional corn hybrids without the additional nitrogen that the latter requires for maximum yield (White et al., 2011).

The abundant biomass and elevated stalk sugar that accumulates in the tropical by tropical cross (high sugar hybrid) originates from both tropical parents and all plant components can be used as an ethanol source. The tropical by temperate cross (dual purpose hybrid) integrates the benefits of high quality grain production and the photoperiod sensitivity of the tropical line, co-producing abundant biomass that can be harvested for use in a bale-burning furnace to produce thermal energy, or that can be ensiled for use as animal feed.

According to Stevenson and Goodman (1972), increased total biomass from delayed flowering and reduced grain production result when maize germplasm adapted to tropical latitudes are grown in temperate regions. Photoperiod sensitivity of the tropical material in temperate regions results from the altered night duration leading to altered development of the crop. Asynchrony occurs when the shedding of pollen from the tassel and the emergence of the silks from the ear of the corn plant occur at different times, and thus reduces the number of silks fertilized by pollen and in extreme cases can eliminate grain production (King et al., 1972). With the stalk as an alternate sink for sugars (Crafts-Brandner et al., 1984), decreased or eliminated grain production causes sugars (sucrose, glucose, and fructose) to accumulate in the corn stalk as a result of no translocation of the sugars into the grain and subsequent conversion of those sugars into starch (Van Reen and Singleton, 1952). Additionally, tropical material remains green longer than temperate germplasm when grain production is limited because it does not undergo accelerated leaf senescence, thus extending photosynthesis and carbon fixation (Betolini et al., 1993).

With forty percent of the corn grain yield in the U.S. consumed for ethanol production (USDA, 2015), exchanging tropical maize as an alternative biofuel source into that grain-ethanol land area has the potential for greater environmental conservation. In the U.S. Corn Belt, producers already have access to and knowledge of equipment for planting corn seed. Tropical maize can also be harvested earlier in the growing season than a traditional grain crop due to the maximum in sugar production and biomass occurring before peak grain yield and dry down of conventional field corn. Earlier harvest allows an extended establishment window for cover crops before frost that could increase the adoption of beneficial cover crops and reduce concerns surrounding above-ground biomass removal.

Hybrid Characterization and Tropical Maize Development

White et al., (2011) crossed open-access temperate by tropical and tropical by tropical inbreds to produce and characterize hybrids for biofuel feedstock potential. Inbreds were selected based on phenotypic traits of high biomass and late maturity dates to increase stalk sugar (Bertolini et al., 1993). Through these crosses, tropical maize was created as a high biomass and stalk-sugar crop. Hybrids were then divided into late and early maturity groups. Earlier maturing hybrids partitioned more biomass to the grain, resulting in a hybrid that would be used for both grain and stover biomass production. Late maturing hybrids were found to partition minimal biomass to grain production, which produced a hybrid with extensive biomass and stalk sugar accumulation (White et al., 2011). Tropical maize hybrids combine open access tropical and temperate genetic materials that have not been selected for ethanol or silage yield, resulting in ample room for future breeding improvements in biomass and sugar accumulation.

Ethanol Production

As of May 2015, Intended Nationally Determined Contributions (INDCs) or pledges by individual countries to the International Energy Agency (IEA) to reduce energy related emissions accounting for 34% of total emissions have been proposed. The United States proposes emission cuts by nearly 30% by 2030. According to the Energy and Climate Change Special Report, the IEA intends the main source of energy for electricity generation to become renewables by 2030 and the “phasing out of fossil-fuel subsidies to end-users” (IEA, 2015).

The Energy Independence and Security Act (EISA) of 2007 seeks biofuel feedstocks that are feasible using modern agricultural practices with acceptance from society and no harmful impacts on the environment (USDA, 2010). The greatest source of biofuel that currently meets these requirements is derived from corn grain. Advancements of cellulosic ethanol conversion technologies have progressed slowly with the first U.S. cellulosic ethanol plant opening in late 2014 (POET, 2014); compared to corn grain ethanol with high volume production as early as the 1970s (Amarasekara, 2013).

Plant-derived biofuels have the potential to reduce carbon emissions and provide a renewable source of energy (Hill et al., 2006). To reduce the release of greenhouse gases in energy production, fossil fuels could be substituted with those derived from carbon neutral plant biomass. There is an 86% reduction in greenhouse gas emissions when ethanol, produced from cellulose powered by biomass byproducts, is used as a fuel source compared to gasoline (Wang et al., 2007).

Oil prices dropped below $50 per barrel in 2015 after being at a stable $100 per barrel in 2014, resulting in challenges of biofuel adoption in the place of fossil fuels. Although there are obstacles, countries have been taking strides in encouraging biofuel use; such as in Brazil, which increased ethanol blending from 25% to 27%, and in Argentina and Indonesia, which implemented mandates to maintain the biofuel industry (IEA, 2015).

Desirable traits sought after in an ideal biofuel crop include genetic resources for improvement, lack of invasiveness, adaptability to latitudinal range, availability of equipment and acceptance by growers (BRDI, 2009). Feedstocks that implement the four-carbon (C4) photosynthetic pathway are most desirable because they have the greatest carbon, water and nitrogen efficiencies (Ragauskas et al., 2006). Three-carbon (C3) crops produce 30% less dry matter per unit of water than C4 crops (Samson and Knopf, 1994). With the same amount of nitrogen, C4 plants produce a four-carbon compound while C3 plants only produce a three-carbon compound and allow photorespiration or the oxygenase reaction to occur, reducing the nitrogen and carbon efficiencies (Lara and Andreo, 2011).

Current alternative biomass crops that use the C4 pathway include perennial grasses such as miscanthus (*Miscanthus x giganteus*), sugarcane (*Saccharum officinarum*), switchgrass (*Panicum virgatum*), and annual grasses such as maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L. Moench) (Yuan et al., 2008). The perennial feedstocks require long-term commitment by producers to one crop, implementation of unfamiliar agricultural practices compared to those of the most common Midwestern US farmer corn-soybean rotation, and development and purchase of new equipment. Perennial bioenergy crops are more nitrogen efficient than annuals with the ability to store reserves in the below-ground structures of the plant during dormancy and recycle nutrients when regrowth begins (Beale and Long, 1997; Lemus et al., 2008). However, perennial grasses such as *Miscanthus* and switchgrass only offer lignocellulose for ethanol production, and in an industry under establishment, this limits current use. In contrast, the annual nature of tropical maize requires no long-term commitment, fitting into the traditional corn-soybean rotation of the Midwestern U.S.

Select C4 crops, including tropical maize, sugarcane, and sweet sorghum, produce three distinct types of harvested carbon: sugar, starch, and lignocellulose biomass (White et al., 2011). Sugarcane has a limited geographic niche with adaption only to warm temperate or tropical areas (Shapouri et al., 2006). Unlike sugarcane, tropical maize and sorghum have a wider range of adaptation. However, there is hesitation to use gene insertion to improve sorghum production due to potential gene flow into its noxious weed relative, johnsongrass (*Sorghum halpense*) (Morrell et al., 2005).

Tropical maize contains many traits of an ideal feedstock (C4 crop, lack of invasiveness, wide geographic range, genetic resources, high biomass potential) (White et al., 2011). Additionally, tropical maize offers an improved energy balance ratio over conventional corn grain ethanol (White et al., 2011). Ethanol produced from conventional corn grain starch has an energy balance of 1.9 to 2.3 (Shapouri, 2011), whereas ethanol produced from all three carbon sources of tropical maize raises the ratio to a range of 8 to 9 (White et al., 2011), which is equivalent to sorghum and sugarcane (Goldemberg, 2007). Although there is variability in maize germplasm, maize and sweet sorghum can yield similar ethanol per hectare (D’ayala et al., 1980).

Forage and Feed Crop

At the core of international food security, there is an increasing global demand for animal protein as global population increases (2-3 billion increase in global population by 2050). Projections show select countries must increase current agricultural land area by 30-50% to support increased livestock production necessary to match this increased demand (Machovina et al., 2015). In meat and feed supply and demand scenarios, future meat consumption has been underestimated (Keyzer et al., 2005). With an increase of 25 million domestic ruminant animals a year for the past half-century (Ripple et al., 2014), nearly 75% of the world's arable land is dedicated to producing ruminants (cropland and pasture) (Foley et al., 2011). Animal feed consumption in developing countries accounts for 42% of the cereal grains produced worldwide (Alexandratos and Bruinsma, 2012). As a result, investigation of alternative animal feed sources has occurred.

The tropical by temperate cross of tropical maize integrates the benefits of modern corn varieties, including improved standability and increased disease and insect pest resistance (White et al., 2011). This cross produces a minimal amount, yet high-quality grain, which can be mixed with the stover, resulting in an ideal candidate for a silage crop to serve as an alternative animal feed source (White et al., 2012). Another alternative silage crop is sorghum, however, it contains dhurrin that can convert into a toxic level of prussic acid (hydrogen cyanide; HCN) (Undersander, 2003) through decomposition, frost, or drought stress of the forage (Dover et al., 2004). Prussic acid can poison and kill ruminants within 15 minutes of ingestion (Stichler and Reagor, 2001).

Silage composition is expressed in terms of dry matter (DM), which is the weight of the silage with all moisture removed. Dry matter intake and energy density directly impact animal performance (Ball et al, 2001). Silage quality can be measured in terms of nutritional and fiber composition. Neutral detergent fiber (NDF) is the part of the silage that is not or only partially digestible, limiting intake, although it is required by ruminant animals. Acid detergent fiber (ADF) is the digestible cellulose but also contains the indigestible lignin portion of the silage. Total digestible nutrients (TDN) directly benefit animal performance and values are calculated with ADF (Shaver and Smith, 2008). Crude protein value is calculated as 6.25 times the total nitrogen concentration of the silage, which is used because ruminant animals can convert any feed nitrogen into usable protein. The number one limiting factor of silage on animal performance is digestible energy (TDN), followed by protein and minerals (Ball et al., 2001). The slightest differences in silage fiber and digestibility compositions result in significant differences in animal performance (Bal et al., 2000). Currently, the average composition of a corn silage hybrid is 47% NDF, 30% starch content coming from the grain component of the silage yielding an average 18 Mg DM ha^{-1} (Lauer et al., 2001).

Animal performance is assessed by body weight changes and body condition scores (BCS). To assess the nutrition of beef cattle, visual BCS are used to assess fat reserves (energy reserves) in a cows' body with a range from 1 = very thin to 9 = obese (Whitman, 1975). The optimum BCS of a mature beef cow is a score of 5 to 7 (Houghton et al., 1990). For moderate conditioned beef cattle, weight changes needed to alter a BCS is between 35-45 kg (Buskirk et al., 1992; NRC, 1996 Lalman et al., 1997).

Sustainable Management

With nearly all of the above-ground biomass of tropical maize removed at harvest to be pressed for simple sugars, baled and burned in a bale burning furnace, ensiled and feed to ruminant animals, or further processed for cellulosic fermentation to produce ethanol, the soil is left nearly barren. With concerns of negative environmental impacts on soil quality and productivity with continual biomass removal (Blanco-Canqui and Lal, 2009), growing tropical maize with environmentally sustainable methods such as conservation tillage, cover crops and reduced fertilizer applications to lessen any negative impacts generated by total above-ground biomass removal is crucial. Although extensive root material remaining after biomass removal can mitigate some of the soil organic matter reductions (Wilhelm et al., 2004), and residue removal from productive soils in continuous corn systems can increase yields in the short term (Coulter and Nafziger, 2008), there is still concern surrounding continual total biomass removal that reduces soil organic carbon, resulting in decreased soil productivity or the ability to support plant growth (Blanco-Canqui and Lal, 2007).

Tillage system

Tillage method can have a positive altering effect on the soil's productivity and soil organic matter. Intensive tillage (conventional tillage) is characterized by a disturbance of the soil surface that leaves less than 15% of plant residue cover after planting. Intensive tillage involves plowing to bury residues, or disking to break clods and dragging, or harrowing. Intensive tillage is practiced to prepare the seed bed, control weeds and establish surface conditions ideal for root development. Conversely, conservation tillage is practiced to minimize incorporation of residue, reducing soil erosion. There is a required 30% of residue that must be present on the soil surface to qualify as conservational tillage (Conservation Technology Information Center, 2002). Benefits include a reduction in fuel consumption, labor cost, and erosion, with improved soil tilth, organic matter, and moisture (Chichester and Richardson, 1992; Tebrugge and During, 1999; Fawcett and Towery, 2002).

Cover Crops and Perennial Ground Cover

Harvest of crops, including corn for silage or lignocellulosic ethanol production, which removes the majority of aboveground plant material, leaves the soil exposed and vulnerable to erosion over winter. Soil erosion is caused by water or wind and is the breakdown, detachment and transport of soil particles and can be reduced by several different conservational practices (NRCS, 2010). The use of cover crops following harvest could prevent or reduce soil erosion. Cover crops are grown to protect and improve soil quality when the cropland is left barren (Brady and Weil, 2008). Benefits of cover crops include erosion control, control of nitrate losses, and water conservation (Blevins et al., 1990). Cover crops can be legumes or cereals that are planted in fall and grown through winter, then killed in spring in order to serve as a source of organic matter and nutrients for the following cropping season (Bollero and Bullock, 1994). Another form of ground cover is that of perennial ground cover or living mulches. These are perennials that are established and maintained in the interrow of a row crop such as corn or soybean (Hartwig and Ammon, 2002). The row crop is harvested and the perennial remains, providing an alternative to leaving land follow and exposing the soil surface (Zemenchik et al., 2000). Perennial ground cover and cover crops provide an intercept of rain drops and wind, thereby reducing the impacts of erosion. Soil aggregation increases as a result of increased organic matter from ground cover, which in turn improves water holding capacity, water infiltration, and soil tilth (Hartwig and Ammon, 2002).

Cover crop establishment in the Midwestern U.S. has been a difficult task due to the relatively late date of harvest of the traditional crops of corn or soybean as compared to necessary seeding timing of cover crops. Winter annuals like annual ryegrass can become established in the cool fall and continue growing after warm up in the spring and must be killed before planting the corn or soybean crop. Typically, cover crops need at least 30 days of establishment, preferably 60 days or more prior to a killing frost, to provide their full benefits (Moncada and Sheaffer, 2010). Unlike the traditional crops of the Corn Belt, tropical maize will be harvested sooner due to the peak in sugar production and biomass earlier in the growing season than traditional peak grain yield and dry down. Thus, the earlier tropical maize harvest sets the stage for the proper 30-60 days window of cover crops establishment before the winter frost that could increase the adoption of beneficial cover crops. Frost seeding, the broadcasting of seed in the late winter (e.g. late February to March), is another timing option for cover crop establishment. The major advantage of frost seeding is the ability to have ground cover prior to the primary crop with no soil disturbance (Undersander et al., 2001; Morrison 2009).

Through a response survey in 2005 concerning cover crop use, out of 1096 producers from Illinois, Indiana, Iowa, and Minnesota, only 8% grew cover crops that year (Singer et al., 2007). In a similar survey conducted in 2010 asking 1360 Iowa producers about cover crop use in the past five years, 12% responded they had used them (Arbuckle and Ferrell, 2012). Both surveys reveal the slow adoption of cover crops in the Midwestern U.S.

Cover crops and perennial ground cover examined in this study were annual ryegrass (*Lolium multiflorum*), pennycress (*Thlaspi arvense* L.), and creeping bentgrass (*Agrostis stolonifera*). Annual ryegrass, also known as Italian ryegrass, is a cool season (C3 plant) annual grass that builds soil structure, scavenges for excess nitrogen and prevents erosion (Clark, 2007). With an extensive dense root system it can minimize soil compaction (Björkman and Shail, 2008). Field pennycress, also known as fanweed, frenchweed, or stinkweed, is a winter annual of temperate regions commonly wide-spread in North America from the Brassicaceae or mustard family (Carr, 1993; Isbell, 2009). Pennycress has attractive qualities as a cover crop because it provides winter cover to sequester nitrogen, spring cover to suppress weeds and is harvestable as an oilseed crop although it is commonly known as a weed in small grain production. The use of pennycress as a cover crop would allow a harvestable oilseed crop (containing 36% oil, which is suitable for biodiesel production) to be grown on land in the Midwestern US year-round without impeding on the growing season of the main crop (Moser et al., 2009). Pennycress can be planted after a corn crop is harvested in the fall, overwinter, and be harvested before a full-season soybean variety without reducing soybean yields (Phippen and Phippen, 2012).

Creeping bentgrass, also known as carpet bentgrass, redtop, or seaside bentgrass, is a cool season perennial with stolons that creep along the ground that is commonly used as a turf grass in golf course fairways (Lowry et al., 2011). Used as a perennial ground cover it has many benefits in an annual row crop system. Hall et al., (1984) showed an 85-100% reduction in soil erosion and surface runoff with the use of perennial ground cover. Additionally, reductions in nitrogen loss by nearly 90% (Liedgens et al., 2004). Overall, consideration of the properties of creeping bentgrass that protect and maintain soil productivity warrant its use in an annual crop rotation. However, with the tendency to reduce corn grain yields, producers typically suppress the growth of perennial ground covers annually, using herbicide to minimize row crop yield reductions from perennial ground cover competition (Martin et al., 1999; Broome et al., 2000).

Determining how cover crops and living mulches impact the biomass accumulation of tropical maize will confirm the compatibility of cover crops and tropical maize. Recognition by producers of the simplicity of cover crop establishment with tropical maize could also encourage adoption of cover crops in the Midwestern U.S.

The objective of this study was to evaluate the compatibility of tropical maize as an alternative biofuel or silage crop when produced with sustainable management practices. To accomplish our objective, we used two hybrids of tropical maize and compared their growth, yield, and/or cattle feed value in response to the rate of fertilizer-applied N and in the presence of a cover crop.

MATERIALS AND METHODS

Plant Biomass and Cover Crops Study

Experimental Design

This experiment was conducted over the years of 2014 and 2015. The experimental design was a split-plot arrangement with ground cover assigned as the main plot treatment, consisting of annual ryegrass, pennycress, creeping bentgrass and no cover. The split plot treatments were tropical maize hybrid (high sugar and dual purpose) and nitrogen rate (0, 67 and 202 kg N ha^{-1}) in each of the four replications. An individual experimental unit (plot) consisted of four rows, 11.4 m (37.5 ft.) in length with 0.76 m (30 in.) spacing. The two center rows of each plot were used for treatment applications and yield measurements.

Field Characteristics

The trial was conducted at the Crop Sciences Research and Education Center in Champaign, IL on a soil that was predominantly a Flanagan silt loam with 0 to 2% slope and with soybean as the previous crop. The field had sufficient levels of P and K based on soil tests that were taken from the plots that did not receive fertilizer (Table 1). In-season soil levels (0 to 15 cm depth) of P, K, Mg, and Ca were extracted using Mehlich III solution with soil testing procedures as per Brown (1998) and are reported as raw means.

Agronomic Management

Tropical by tropical (high sugar) and tropical by temperate (dual purpose) hybrids were planted with an ALMACO SeedPro 360 planter (ALMACO, Nevada, IA) to achieve an approximate final stand of 86,500 plants ha^{-1} (35,000 plant acre^{-1}). The site was planted April 23rd, 2014 and May 14th, 2015. A replant occurred in 2014, on May 25th with the high sugar hybrid, due to poor germination. Blocks of cover crops were broadcast (frost seeded) at a seeding rate of 17 kg ha^{-1} for annual ryegrass, 6 kg ha^{-1} for pennycress, and 37 kg ha^{-1} for creeping bentgrass for each year of the trial. Due to the timing of field assignments at the Center, cover crops were not sown until late winter each year. Weed control in 2014 consisted of only a post-emergence application of 365 mL hectare^{-1} of Status (BASF, North Carolina, US) [dicamba: 3,6-dichloro-2-methoxybenzoic acid, sodium salt; diflufenzopyr: 2-(1-[([3,5-difluorophenylamino] carbonyl)-hydrazono]ethyl)-3-pyridinecarboxylic acid, sodium salt], plus 54.75 mL hectare^{-1} of Armezon (BASF, North Carolina, US) [topramezone: [3-(4,5-dihydro-isoxazolyl)-2-methyl-4-(methylsulfonyl)phenyl](5-hydroxy-1-methyl-1H-pyrazol-4-yl)methanone], and 3.5 L hectare^{-1} Prowl H_2O (BASF, North Carolina, US) [pendimethalin: N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] to terminate the annuals, and an application of Status alone on the perennial ground cover. In 2015, pre-emergence weed control consisted of Touchdown (Syngenta, Basel, Switzerland) [glyphosate: N-(phosphonomethyl) glycine] as a burndown for all weeds. Post-emergence weed control on the annuals was 54.8 mL hectare^{-1} of Armezon, plus 1 kg hectare^{-1} of AAtrex Nine-O (Syngenta, Basel, Switzerland) [atrazine: 2-chloro-4-ethylamino-6-isopropylamino-s-triazine], along with 18.7 L hectare^{-1} of surfactant Methylated Seed Oil (MSO), and 3.7 L hectare^{-1} of ammonium sulfate, and Status alone on the perennial ground cover. Nitrogen treatments of 0, 67, and 202 kg N ha^{-1} were applied at the V4 growth stage by hand applying urea [$CO(NH_2)_2$, 46-0-0] and allowing it to incorporate with rainfall.

Tropical Maize Plant Sampling, Processing and Data Collection

Prior to harvest, stand and lodging counts were conducted to determine the final plant populations of the plots. Harvest sampling consisted of manually excising five plants at the soil surface from the center two rows of each plot at growth stages R4 (high sugar) and R6 (dual purpose) to determine total above-ground biomass. Hybrids were sampled at the same date, but the tropical by tropical (high sugar) hybrid exhibited delayed maturation. The plants were partitioned into grain and stover (including husk) components, and biomass was determined by weighing the total fresh stover then processing it through a Vermeer BC600XL chipper (Vermeer Corporation, Pella, IA) to obtain representative stover subsamples. The stover subsamples were immediately weighed to determine aliquot fresh weight (FW), and then weighed again after drying to 0% moisture in a forced air oven at 75°C, to determine subsample aliquot dry weight (DW) and calculate stover moisture content (MC) by Equation 1.

$$\%MC = \left(\frac{FW - DW}{FW}\right) x\ 100 \tag{1}$$

The corn ears with grain were dried and then weighed for grain and cob weight. The grain was removed using a corn sheller (AEC Group, St Charles, IA) and analyzed for moisture content using a Dickey John moisture reader (GSF, Ankeny, IA). Cob weight was obtained by difference, and dry leaf and stalk weights were summed to calculate the overall mass of dry stover.

Equation 2 was used to estimate total dry weight (TDW) from subsample moisture concentration (%MC) and total fresh weight (TFW) of the plant.

$$TDW\ =\ Grain\ dry\ weight + cob\ dry\ weight + \left[TFW\ x\ \left(\frac{\%MC}{100}\right)\right] \tag{2}$$

Total biomass and grain yield per area were derived algebraically from TDW biomass per plant and stand counts, and is expressed as Mg ha^{-1} on a dry weight basis (i.e., 0% moisture).

Ground Cover Sampling and Data Collection

In-season ground cover (creeping bentgrass) was sampled for mulch biomass using a 0.25 m^2 quadrat and hand shears. Mulch samples were obtained as close as possible to the date of the tropical maize sampling from areas near the ends of each plot, which were not part of the final harvestable area, and were sampled as close to ground level as possible. All samples were dried to 0% moisture and weighed. Area biomass was extrapolated using this subsample dry weight and whole plot area.

Statistical Analysis

The analysis used on all the traits measured was carried out with SAS software using the PROC MIXED procedure (Version 9.4; SAS Institute, 2013) and significance was declared at $P \leq 0.10$ unless otherwise noted. Statistics were declared significant by evaluating differences with fixed effects being hybrid, block (ground cover), and nitrogen rate. Year and replication were included as random effects. All treatments were used in 2014 and 2015 to evaluate the effect of cover crop and N rate and their interactions with tropical maize hybrid. PROC UNIVARIATE was used to determine potential outliers and assess normality of residuals.

Animal Feeding Study

Animal Feeding Measurements and Results

In 2014 and 2015 a separate 60-day animal feeding study was conducted by Dr. Daniel Shike to compare the feed quality of ensiled tropical maize and conventional field corn on animal performance. The evaluation consisted of 48 post-calving Angus cows fed a diet of tropical maize (dual purpose hybrid) compared to conventional corn silage. To obtain the silage, 1.2 hectares (3 acres) of tropical maize and 1.2 hectares of conventional field corn were drilled to achieve a final stand of 172,970 plants ha^{-1} (70,000 plants acre^{-1}) on May 22nd, 2013 and planted to achieve a final stand of 88,956 plants ha^{-1} (36,000 plants acre^{-1}) on May 27th, 2014 at the Animal Sciences research farm in Champaign, IL. To simulate a standard producer's practice, tropical maize received 67 kg N ha^{-1} and conventional corn silage received 202 kg N ha^{-1} pre-plant in 2013 as anhydrous ammonia. However, both crops received 157 kg N ha^{-1} as anhydrous ammonia in the early spring of 2014 due to an application error, with an additional sidedress of 45 kg N ha^{-1} as urea ammonium nitrate to the conventional corn silage alone. The corn was chopped and bagged to be ensiled at the R4 growth stage on September 9th, 2013 (fed in early 2014) and September 17th, 2014 (fed in early 2015).

Between February and April, Angus beef cows were fed a mixture of 75% silage, 20% MDGS (modified distillers grains with solubles), with a 5% vitamin and mineral supplement. They were evaluated for body weight (BW) and body condition scores (BCS) at the start and end of the three- month period. A sample of each silage type was taken in February and compositional analysis was done at Analab (Agri-King, Inc., Fulton, IL). Initial BW was measured after calving and final BW was measured 60 days later, with the difference used to calculate BW change. Body condition scores were assessed on a scale ranging from 1 = very thin to 9 = obese (Whitman, 1975). In 2014 cows were limit-fed 13 kg cow^{-1} day^{-1}, however, in 2015 cows were offered feed ad libitum.

Each year there were 6 pens of 4 Angus beef cows fed each silage treatment. The experimental unit used for statistical analysis was a pen of four cows, analyzed in Proc MIXED in SAS (Version 9.4; SAS Institute, 2013).

RESULTS AND DISCUSSION

Weather Conditions

With below-average temperatures and above-average precipitation throughout much of the 2014 growing season, the crop experienced little weather-induced heat or moisture stress (Table 2). As a result, conditions were generally conducive to above-average biomass production and grain yields. The growing conditions in 2015 were similar with above average precipitation in May and June (Table 2).

Biomass Production: Perennial Ground Cover

The perennial creeping bentgrass ground cover produced similar amounts of biomass yields regardless of the nitrogen rate (Table 3). The amount of dry matter produced is indicative of complete ground coverage (Bowman and Scott, 2009), which was verified by visual observations (Figure 2).

Biomass Production: Tropical Maize

Ground cover and nitrogen rate treatments significantly influenced tropical maize biomass yield averaged across the random effect of year (P <0.001; Table 4). The greatest tropical maize biomass accumulations across the 2014 and 2015 growing seasons were achieved with the high sugar hybrid in combination with annual or no ground cover and with 202 kg N ha^{-1} of supplemental nitrogen (average of 19.0 Mg ha^{-1}; Table 5). These biomass yields are comparable to other biomass feedstocks such as switchgrass (15 Mg ha^{-1}) (Parrish and Fike, 2005) and *Miscanthus* (20+ Mg ha^{-1}) (Lewandowskia et al., 2000). However, unlike switchgrass and *Miscanthu*s with tropical maize, there is no multi-year commitment for producers and harvestable material is available for income prior to the second or third growing season. When *Miscanthus* is harvested at maximum biomass (October), nutrient removal rates are greater than with winter harvest (February) due to nutrient cycling, however, biomass yields at the recommended winter harvest are reduced to 12-18 Mg ha^{-1}. The nitrogen requirement with winter harvest in *Miscanthus* is 76 kg ha^{-1}; however, to obtain maximum biomass yields the nitrogen requirement reaches 167 kg ha^{-1} (Cadoux et al., 2012). The optimal production system for switchgrass with a recommended 65-90 kg N ha^{-1} depending on harvest time only produced 12 Mg ha^{-1} yr^{-1} (Haque et al., 2009; Haque and Epplin, 2010). As a result, tropical maize is achieving similar biomass yields at a lower nitrogen requirement (15-16 Mg biomass ha^{-1} with 67 kg N ha^{-1}; Table 5) compared to other common biomass feedstocks.

Annual cover crops had minimal impact on biomass production of tropical maize, suggesting compatibility in the tropical maize cropping system (Table 5). Supplemental nitrogen increased above-ground biomass yield of tropical maize in all hybrid and ground cover combinations. Regardless of nitrogen regime or tropical maize hybrid selection, harvest for sugar, starch, or biomass accumulation can occur as early as R4. By harvesting the tropical maize at this growth stage, adequate time exists for cover crop seeding and establishment in the Midwestern U.S. before the normally fallow wintertime (Moncada and Sheaffer, 2010).

When grown with no supplemental nitrogen, neither annual cover crop changed the biomass accumulation of tropical maize compared to the no cover crop control. However, the two hybrids grew differently in response to cover crop and nitrogen management changes. Visual in-season differences between the tropical by temperate (dual purpose hybrid; Figure 1A) and the tropical by tropical cross (high sugar hybrid; Figure 1B) were readily apparent. At 67 kg N ha^{-1}, when grown with the pennycress treatment the high sugar hybrid produced significantly less biomass than when grown with annual ryegrass or the no cover control (Table 5; reductions $\geq$ 3.0 Mg ha^{-1}). Biomass accumulation of the high sugar hybrid may have been restricted by nutrient immobilization or an allelopathic effect (chemical inhibition of one plant species by another) from pennycress (Torres et al., 1996). Nutrient immobilization is greater in conservation tillage management, caused when soil nitrogen is not yet available to the row crop (Dabney et al., 2001), due to nitrogen release rates of cover crop residue increasing with tillage incorporation and varying by residue composition (Wilson and Hargrove, 1986). Additionally, pennycress contains glucosinolate sinigrin which can be hydrolyzed to form chemicals that may produce an allelopathic effect; Vaughn et al., (2005) found it to inhibit seedling germination and emergence in wheat, reducing biomass yields.

When grown with the perennial ground cover (creeping bentgrass), the high sugar hybrid produced significantly less biomass than when grown with any other ground cover regardless of nitrogen rate (Table 5). At 0 and 67 kg N ha^{-1}, the dual purpose hybrid produced similar biomass in both annual cover crops, with statistically reduced yields with perennial ground cover. However, when grown at the highest level of nitrogen, the dual purpose hybrid had similar biomass production irrespective of ground cover treatment. Additional competition from the perennial ground cover may have been overcome by the inherent increased grain production of the dual purpose hybrid.

With no supplemental nitrogen, the perennial ground cover significantly reduced biomass accumulation in both hybrids, suggesting suppressed growth resulting from in-season ground cover competition. The period of time after corn emergence to V5 or extended to VT (Evans et al., 2003) is the critical period when weeds must be suppressed to maximize yield potential (Rajcan and Swanton, 2001). Although not a weed to a producer, this perennial ground cover growth overlaps the critical period of weed control, and similarly effects tropical maize growth. Additionally, avoidance of the perennial ground cover shade which alters the plant structure could also reduce plant growth (Rajcan et al., 2004). To reduce the impacts of competition for nutrients and light by a perennial ground cover on a row crop, producers can use herbicide and strip tillage control (Masiunas, 1998; Martin et al., 1999; Broome et al., 2000) as well as proper ground cover selection (Paine and Harrison, 1993).

Grain Yield

Grain production for both hybrids significantly increased with each increase in nitrogen fertilizer rate, consistent with conventional corn hybrids (Table 6) (Pierre et al., 1977; Anderson et al., 1984). White et al., (2012) found that with additional nitrogen, grain production increased in tropical maize and partitioned less biomass to the stalk; nevertheless, it partitions more biomass to the stalk than conventional field corn. Although increasing nitrogen fertilizer increases grain yield, the process of making the starch for yield decreases stalk sugar concentration. Without additional nitrogen, tropical maize has five times the stalk sugar concentration than conventional field corn (White et al., 2012).

The dual purpose hybrid yielded significantly greater corn grain than the high sugar hybrid at all nitrogen rates (Table 6). Supplemental nitrogen had a greater effect on the grain yields of the dual purpose hybrid than any of the ground cover treatments, with increasing nitrogen promoting greater yields. Furthermore, grain yield of the dual purpose hybrid significantly declined when grown with the perennial ground cover and when grown with no, or low levels of fertilizer nitrogen.

Characterized for ethanol production, the high sugar hybrid does not naturally produce grain when grown in a temperate environment; rather, increased vegetative biomass and sugar accumulation occurs. Minimal grain was produced by the high sugar hybrid (Figure 1C; Table 6).

With no supplemental nitrogen, the dual purpose hybrid produced more grain than the high sugar hybrid, even when it was provided the highest rate of nitrogen fertility.

Animal Weights and Condition Scores

Tropical maize (dual purpose hybrid) and conventional corn silage tended to have comparable crude protein and total digestible nutrients (TDN) (Tables 7). These silage fractions are the top two limiting factors in animal performance (Ball et al., 2001). Both silage types produced feed with components in acceptable ranges for animal consumption. Starch concentration was consistently less in the dual purpose hybrid compared to the conventional hybrid due to the tropical component limiting grain production. Silage production year (environment) altered the composition for both tropical maize and conventional corn (Tables 7). The year 2014 had excellent growing conditions and record yields; therefore, the traditional silage had a greater proportion of grain and starch in that year. However, tropical maize had limited grain production in both years and less compositional variation between the years, potentially a positive attribute for a silage feedstock.

Angus cattle body weight gain was similar when fed for 60 days with tropical maize silage compared to conventional corn silage (Tables 8). Weight gains were less with a limit-fed diet in 2014 than in 2015 when cows had access to more silage per day. Quality assessment indicated tropical maize was at least as palatable as conventional corn silage. In 2014, there was no improvement in body condition scores (BCS), while in 2015 there was a one point increase in BCS when cows had ad libitum access to the feed. The voluntary access only resulted in 1 kg per day extra intake per animal. Perhaps, if the feeding study was continued more than 60 days, a greater change would have been observed in cattle weight and BCS from feeding dual purpose tropical maize.

CONCLUSIONS

As an annual which is genetically, structurally, and biologically similar to commercial field corn, tropical maize can be managed and planted with the same equipment as conventional field corn, giving it a major advantage over other bioenergy crops. Additionally, it fits into the most common crop rotation in the U.S. Corn Belt, which is a corn-soybean rotation. With this ability, tropical maize can utilize many aspects of the infrastructure and technology supporting corn grain and ethanol production, thereby simplifying its implementation relative to other alternative crops. Having the flexibility to use sustainable practices, such as cover crops and conservation tillage will increase the likelihood of tropical maize adoption by producers.

Tropical maize has properties that could make it a competitive bioenergy feedstock. Total above-ground biomass yields are equivalent to conventional methods and were achieved when sustainably growing tropical maize in combination with conservation tillage and annual cover crops. However, use of perennial ground cover must be controlled to reduce inter-cropping system competition. With the progression of cellulosic ethanol conversion technology, the superior biomass accumulation obtained with sustainable management practices of tropical maize makes it an excellent candidate for an alternative fuel source.

The tropical by temperate cross of tropical maize produces an ideal dual purpose hybrid with extensive leafy biomass and quality grain, and silage that performs well as an alternative animal feed. With nutritional quality comparable to that of conventional corn silage, high palatability, and reduced nitrogen fertilizer requirements, tropical maize can serve as a low-input, high quality silage source, with no hindrance of animal performance.

TABLES AND FIGURES

Table 1. In-season soil test results for each field of the tropical maize trial conducted in Champaign, IL during 2014 and 2015. Soils tests were conducted to assess baseline soil fertility at a depth of 0 to 15 cm.

Cover	Organic Matter	CEC	pH	P	K	Ca	Mg
	%	meq/100g	units		ppm		
2014	3.4	18.0	6.2	32	130	2345	357
2015	2.7	26.9	5.2	21	95	2735	481

Table 2. Monthly weather data between 1 May and 30 September for Champaign, IL in 2014 and 2015. Temperature °C is the average daily temperature and Precipitation (cm) is the average monthly accumulated rainfall. Values were obtained from Illinois State Water Survey (2015) and values in parentheses are the deviations from the 20-year average (1993-2012).

	Month				
Year	**May**	**June**	**July**	**August**	**September**
2014					
Temperature, °C	17.9 (+1.0)	23.0 (+0.9)	21.1 (-3.0)	23.1 (+0.1)	18.3 (-0.7)
Precipitation, cm	11.1 (-0.6)	20.9 (+10.2)	22.1 (+11.7)	3.9 (-5.0)	8.7 (+0.5)
2015					
Temperature, °C	18.9 (+2.1)	22.5 (+0.4)	23.3 (-0.7)	22.4 (-0.6)	20.9 (+1.9)
Precipitation, cm	15.4 (+3.8)	22.9 (+12.2)	10.6 (+0.2)	8.0 (-0.8)	16.4 (+8.2)

Table 3. Effect of nitrogen fertilization rate on the biomass production of creeping bentgrass when grown as a cover crop in tropical maize. Values are the average of two years at Champaign, Illinois in 2014 and 2015.

N Rate	**Biomass**
kg ha^{-1}	
0	1038
67	1105
202	1137
LSD (α=0.10)	NS

Table 4. Analysis of variance for fixed effects on total above-ground biomass production and grain yield for the tropical maize trial evaluated at Champaign, Illinois in 2014 and 2015 with year and replication as random effects.

Fixed Effect	**Biomass**	**Grain Yield**
	P* > *F	
Cover (C)	<0.001	0.022
Hybrid (H)	0.632	<0.001
C x H	0.008	0.105
Nitrogen (N)	<0.001	<0.001
C x N	0.513	0.419
N x H	0.226	<0.001
C x H x N	0.657	0.319

Table 5. Effect of nitrogen fertilization rate and cover crop on total above-ground biomass accumulation of tropical maize measured at the R4 (high sugar hybrid) and the R6 (dual purpose hybrid) growth stages at Champaign, IL in 2014 and 2015. Values are the average of the two years and are expressed on a dry weight (0% moisture) basis.

	Nitrogen Rate (kg N ha^{-1})		
Ground Cover	**0**	**67**	**202**
	Mg ha^{-1}		
High Sugar Hybrid			
No Cover	10.7 a	16.0 a	18.9 a
Annual ryegrass	10.7 a	15.1 a	19.1 a
Pennycress	9.6 a	12.1 b	16.7 ab
Creeping bentgrass	5.8 b	7.7 c	14.9 b
Average	9.2 C	12.7 B	17.4 A
Dual Purpose Hybrid			
No Cover	11.1 a	15.0 a	17.3 a
Annual ryegrass	10.6 a	13.1 ab	16.7 a
Pennycress	10.9 a	14.1 ab	17.6 a
Creeping bentgrass	6.6 b	11.6 b	15.1 a
Average	9.8 C	13.4 B	16.6 A

*Mean separation tests were conducted using an LSD calculation with the Tukey adjustment. Lower case letters compare treatments within a nitrogen rate for each hybrid, upper case letters compare the main effect of nitrogen within a hybrid. Similar letters are not significantly different at α=0.05.

Table 6. Effect of nitrogen fertilization rate and cover crop on grain yield of tropical maize measured at the R4 (high sugar hybrid) and the R6 (dual purpose hybrid) growth stages at Champaign, IL in 2014 and 2015. Values are the average of the two years and are expressed on a dry weight (0% moisture) basis.

	Nitrogen Rate (kg N ha^{-1})		
Ground Cover	**0**	**67**	**202**
	kg ha^{-1}		
High Sugar Hybrid			
No Cover	96 a	517 a	974 a
Annual ryegrass	170 a	578 ab	1093 a
Pennycress	81 a	378 ab	788 a
Creeping bentgrass	74 a	210 b	1224 a
Average	105 C	421 B	1020 A
Dual Purpose Hybrid			
No Cover	2696 a	5269 a	7074 a
Annual ryegrass	2920 a	4840 a	6327 a
Pennycress	2070 ab	4803 a	6305 a
Creeping bentgrass	1390 b	4892 a	6377 a
Average	2269 C	4951 B	6520 A

*Mean separation tests were conducted using an LSD calculation with the Tukey adjustment. Lower case letters compare treatments within a nitrogen rate for each hybrid, upper case letters compare the main effect of nitrogen within a hybrid. Similar letters are not significantly different at α=0.05.

Table 7. Compositional quality of ensiled tropical maize (dual purpose hybrid) and conventional field corn silage produced in Champaign, IL during 2013 (fed during 2014) and 2014 (fed during 2015). All units are expressed on a dry weight (0% moisture) basis.

Parameter	Tropical	Traditional
	%	
2014		
Dry Matter	30.7	31.5
Crude Protein	7.5	8.0
ADF	31.3	25.5
NDF	51.8	42.9
Starch	17.3	25.3
TDN	62.5	67.5
2015		
Dry Matter	22.9	30.2
Crude Protein	7.6	7.5
ADF	33.1	23.2
NDF	55.7	39.9
Starch	17.9	35.5
TDN	61.1	69.2

*Average fresh weight at harvest was 33.6 and 69.4 Mg ha^{-1} in 2013 and 2014, respectively.

Table 8. Effect of feeding tropical maize or conventional corn silage on the body weight (BW) and body conditioning scores (BCS) of angus cattle fed in Champaign, IL in 2014 and 2015. The BW is expressed in kg cow^{-1} on a dry weight (0% moisture) basis. The BCS are on a scale of 1 = emaciated to 9 = obese. In 2014, cattle received a restricted feeding of 13 kg cow^{-1} day^{-1}, while in 2015, cattle voluntary dry matter intake (DMI) was 14 kg cow^{-1} day^{-1}.

Parameter	Tropical	Conventional	P-value
2014			
Initial BW	658	681	0.34
Final BW	679	694	0.49
Weight Δ	20	12	0.37
Initial BCS	6.0	6.0	0.89
Final BCS	5.9	5.8	0.75
BCS Δ	-0.1	-0.2	0.92
2015			
Initial BW	640	637	0.86
Final BW	725	713	0.62
Weight Δ	85	77	0.31
Initial BCS	5.9	5.8	0.39
Final BCS	6.9	6.8	0.19
BCS Δ	1.0	1.0	1.00

Figure 1. Tropical maize hybrid differences in the growing season at Champaign, IL. The dual purpose hybrid at VT/R1 (A) and the high sugar hybrid at R4 (B). Developmental differences in grain formation, the dual purpose hybrid develops grain (left) while the high sugar hybrid does not (left) (C).

Figure 2. In season establishment of perennial ground cover (creeping bentgrass) with tropical maize at Champaign, IL.

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