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Integration of Optical Remote Sensor-Based Yield Prediction and Impact of Nitrogen Fertilization, Harvest Date, and Planting Scheme on Yield, Quality, and Biomass Chemical Composition in Energy Cane Production in Louisiana

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Abstract

The established sugarcane industry in Louisiana is perceived as an advantage for biofuel industry because of the similarities of energy cane and sugarcane by way they are cultivated, harvested, and processed. This study was conducted at the LSU AgCenter Sugar Research Station in St. Gabriel, LA from 2013-2015 to evaluate the influence of planting scheme, N rate, and harvest date on energy cane yield, quality parameters, nutrient uptake, and biomass chemical composition. The relationship of vegetation indices (VI) with stalk, fiber yield, and N uptake of energy cane harvested at different dates was also evaluated. The experiments consisted of variety (Ho 02-113, US 72-114), N rate (0, 56, 112, and 224 kg N ha^{-1}) and harvest date (one- and two-months earlier harvest and scheduled harvest) as treatments arranged in split-split plot in a randomized complete block design with four replications. Another experiment was conducted with planting scheme (whole stalks vs. billets) and variety (Ho 02-113, US 72-114, Ho 06-9001, Ho 06-9002, L 01-299, and L 03-371) as factors arranged in split plot in randomized block design with four replications. Energy cane yield, quality parameters, chemical composition, and nutrient concentration and uptake were significantly affected by harvest date only. Both N rate and planting scheme did not affect biomass yield and quality. The nutrient removal rates between planting scheme were similar but not among harvest dates and varieties suggesting that the fertilizer recommendation will remain virtually the same for whole stalk- and billet-planted energy cane. The Pearson correlation analysis showed a strong dependence between VIs (i.e., simple ratio, normalized difference vegetation index) computed from reflectance readings at 670 (red) and 705 (red-edge) nm and stalk yield, N uptake, and fiber yield across cane age. The outcomes of this study show the: a) applicability of sugarcane cultural management practices for energy cane production, b) potential use of optical remote sensing in energy cane stalk and fiber

yield prediction, and c) several areas of research emphasis to pursue for future studies on energy cane.

Chapter 1. Introduction

1.1 History and current situation of biofuel

Biofuels and bioenergy are not a recent discovery it is as old as civilization itself. Solid biofuels, such as wood, charcoal and dried manure, have been used ever since man discovered fire (Songstad et al. 2009). Liquid biofuels derived from plants and animals, such as whale oil and olive oil, have been used as lamp oil since early ancient times. The internal combustion engine, invented by Samuel Morey (US Patent 4378 Issued April 1, 1826), was designed to run on a blend of ethanol and turpentine (derived from pine trees) (Songstad et al. 2009). Petroleum or crude oil has also been used since ancient times in various forms; the first commercial oil well has been attributed to Edwin Drake in 1859 near Titusville, Pennsylvania, USA (Kovarik 1998). Also developed and commercialized in the mid-19th century was kerosene, which became the first combustible hydrocarbon liquid (Kovarik 1998). During World War I, there were fossil/oil shortages, and therefore ethanol was in high demand, as it became known that ethanol could be blended with gasoline for a suitable motor fuel (Kovarik, 1998; Songstad et al., 2009). Biofuels were the primary energy source until coal became available on a large scale in the developed world in the late 19th century (Fernandes et al. 2007). In the developing world, solid biofuels continue to be used as an important source of heat and cooking fuel (Fernandez et al., 2007).

From early seventies to nineties, there have been several fossil/oil crises that prompted renewed interest in biofuels: the oil crisis caused by the Organization of Arab Petroleum Exporting Countries (OAPEC) oil export embargo (1973), the Iranian Revolution (1979), and oil price shock caused by the Gulf War (1990). These crises led many countries, such as the US and Brazil to begin modern large-scale production of biofuels originating from bio-renewable sources including sugars, starches and lignocellulosic materials (Sheehan et al., 1998; Current State and Prospects, 2006). In the last ten years, biofuels have been embraced as a way to help resolve some of the world's greatest challenges: declining fossil fuel supplies, high oil prices and climate change (Fernandez et al., 2007).

The agreement implemented by Policy Energy Act (PEA) followed by the Energy Independence and Security Act (EISA) in 2005 aims to reach 136.27 billion liters of bioethanol by the year 2022. Several countries have initiated new alternatives for gasoline from renewable feedstocks (Goldemberg, 2007). In the U.S and North American, bioethanol is primarily produced from corn starch feedstocks while from sugarcane/sugar beets juice and molasses in Brazil and other South American countries (Wheals et al., 1999). The U.S and Brazil account for 89% of the current global bioethanol production (RFA, 2010). European countries are deploying extensive efforts to increase their 5% worldwide bioethanol production (Gnansounou, 2010). France and Germany remains by far more substantial in producing biofuel mainly biodiesel and accounts for approximately 56% of the global production because of the rising importance of diesel engines and feedstock opportunity costs (EU, 2009). China, Thailand as well as India are continuing to invest substantially in agricultural biotechnology and emerge as potential biofuel producers (Swart et al., 2008; Licht, 2008).

The global production and use of biofuels have increased dramatically in recent years, from 18.2 billion liters in 2000 to 60.6 billion liters in 2007, with about 85% of this for bioethanol (Coyle, 2007). Worldwide increasing interest in the production of bioethanol is exemplified by production of 85 billion liters of bioethanol in 2011 (Singh and Bishnoi, 2012; Avci et al., 2013).

Although the first generation biofuels like bioethanol production is estimated to increase to more than 100 billion liters by 2022 (Goldemberg and Guardabasi, 2010; Goldenberg, 2007), the sourcing of these raw materials competes with food and has impacted land use and biodiversity, which is not sustainable to meet the increasing demands for fuels (Hahn-Hagerdal et al., 2006). With these pressing issues, the second-generation biofuels produced from lignocellulosic biomass can offer a great potential for biofuel industries (Simpson-Holley et al., 2007). Lignocellulosic materials such as agricultural residues, wood, paper waste , and dedicated energy crops (miscanthus, switchgrass, sweet sorghum, energy cane, etc.) makes up the majority of the cheap and abundant nonfood materials available from plants (Claassen et al., 1999). This is because the lignocellulosic materials can be collected or harvested several times without annual planting, which significantly reduces average annual costs for establishing and managing energy crops as compared to conventional crops (Franks et al., 2006). The global production of plant biomass, of which over 90% is lignocellulose, amounts to about 181 x 10^9 Mg per year, where about 5 to 10% of the primary biomass remains potentially accessible (Kuhad and Singh, 1993).

Lignocellulosic material generally divided into three main components: cellulose (30-50%), hemicellulose (15-35%), and lignin (10-20%) (Pettersen, 1984; Badger, 2000; Mielenz, 2001; and Girio et al., 2010). Cellulose is a glucose polymer, consisting of linear chains of (1,4)-D-glucopyranose units, in which the units are linked 1–4 in the β-configuration, with an average molecular weight of around 100,000 Da. Cellulose fibers are linked by a number of intra- and intermolecular hydrogen bonds (Li et al., 2010). Therefore, cellulose is insoluble in water and most organic solvents (Swatloski et al., 2002). Hemicellulose is a mixture of polysaccharides, composed almost entirely of sugars such as glucose, mannose, xylose and arabinose and methyl glucuronic and galaturonic acids, with an average molecular weight of < 30,000 Da. They are relatively easy to hydrolyze because of their amorphous and branched structure (with short lateral chain) as well as their lower molecular weight (Li et al., 2010). In order to increase the degradability of cellulose, large amounts of hemicelluloses need to be removed from cellulose fibrils to enhance enzymatic hydrolysis (Agbor et al., 2011). Lignin is an aromatic and rigid biopolymer with a molecular weight of 10,000 Da bonded via covalent bonds to xylans (hemicellulose portion) conferring rigidity and high level of compactness to the plant cell wall (Girio et al., 2010). Lignin is composed of three phenolic monomers of phenyl propionic alcohol namely, coumaryl, coniferyl and sinapyl alcohol.

It is recognized that 2^{nd} generation biofuels generally have several advantages over both fossil fuels and 1^{st} generation biofuels. These include reduced greenhouse gas (GHG) emissions, a more positive energy balance, and better access to sustainable biomass feedstocks all-year-round. Thus, it will keep the conversion plant working and hence spread the annual overhead costs over a greater number of liters of biofuel produced (AEA, 2008). The growing interest in bioenergy in recent decades pushed scientists to better understand the plant's physiological source-to-sink process as an obvious step to get efficiency either in the process of capturing solar energy by the plant which can lead to the forms for increasing the sucrose content, cell wall synthesis and increasing degradation in biomass (Lingle, 1999; Waclawovsky et al., 2010; de Souza et al., 2013). In general, the characteristics of the ideal energy crop would require high yield (maximum production of dry matter per hectare) and low energy input. This is due to its high conversion efficiency of light into biomass energy, high leaf level of nitrogen and water use efficiency as well as low production costs, contaminants, and nutrient requirement (McKendry, 2002; Taylor et al., 2010).

With the persistent interest in biomass energy (US DOE, 2011), the traditional sugarcane breeding programs of U.S mainland continued to progress with their energy cane breeding programs. One of the leading crops being considered in Louisiana as a biofuel feedstock is energy cane. Energy cane is somewhat similar to sugarcane but energy cane has a lower sucrose content and higher fiber content than sugarcane varieties grown in the state, and most importantly, it has higher expected yields in terms of metric tons of plant material per hectare (Salassi et al., 2013). Furthermore, energy cane has a narrower leaf blade, thinner stalk, and high number of tillers per stool both plant cane and ratoon crops than sugarcane (Alexander, 1985; Wang et al., 2008; Shang et al., 1969; Panje, 1972). The higher the number of tillers the better the ratooning ability thus, increase in total yield over the whole cropping cycle. This is very important both in economic and environmental terms (Matsuoka and Stolf, 2012).

As a result, the Louisiana program succeeded in releasing three cultivars (Bischoff et al., 2008; Tew et al., 2007) and others are still under the development. Korndorfer (2011) found energy cane is more appropriate than giant reed (*Arundo donax* L.) as a bioenergy feedstock in sandy soils of south Florida. Duval et al. (2013) confirmed energy cane can produce better in the spodosol (sandy soil) than in the histosols (muck soils) if carbon (C) sequestration was taken into account. Additionally, Álvarez and Helsel (2011) concluded that energy cane has potential to become a useful bioenergy crop in Florida’s unmanaged mineral soils. Presently there is a joint effort by specialists from eight states of Southeastern USA to evaluate energy cane and other feedstocks, from field to industry (SUBI, 2012). They obtained encouraging results of yields from the experiments established north (latitudes up to 33°N) of the traditional sugarcane growing regions (Richard et al., 2010; Viator et al., 2010). In their survey more than 1,500 thousand hectares were identified as potential locations to grow energy cane, which is almost twofold the area today devoted to sugarcane in USA (SUBI, 2012).

1.2 Energy cane production in Louisiana

Louisiana has a semi-tropical climate (average temperature of 19°C), adequate water (average annual precipitation of 162.6 cm), and fertile organic soil (alluvial) which is favorable for the production of a wide variety of energy crops for biofuel (Kim and Day, 2011). Louisiana is known as the oldest and largest commercial sugar cane industry in the United States and already has bio-refineries in the form of raw sugar mills. The presence of existing infrastructure that supports Louisiana's $2 billion sugarcane industry and expertise in producing sugarcane would give a better prospects for energy cane production than a comparative other potential nontraditional feedstock crops (Baldwin et al., 2012). This may provide an opportunity to expand the operational season for Louisiana sugar mills and to generate biofuel. Since sugarcane and energy cane are somewhat similar in characteristics; planting and harvesting are implemented in the same manner as presently applied for sugarcane production. Energy cane is a semi-perennial grass vegetatively propagated; meaning it regrows for several years after initial planting. The initial crop planted around August to September is harvested approximately 14 months later (plant cane). Then sugarcane is harvested on an 11 month cycle for an additional 3 to 4 years (ratoon sugarcane). Furthermore, both feedstocks can be processed in conventional sugar mills, where juice has to be extracted in a primary processing plant prior to considering lignocellulosic processing (Aragon et al., 2013).

In Louisiana, the traditional way of planting sugarcane was with the used of whole stalk in order to overcome an often harsh winter climate and stalk rot damage (Hoy et al., 2004). Planting is usually done in late summer months (August – September) and starts to germinate and produce shoots but ceases its growth during winter months (December-January) due to saturated soils and several freezes. However, the high cost of labor and equipment required in whole stalk planting makes this planting method less popular. For these reasons, the adoption of the billet planting was of great interest.

Planting is the most expensive operation in cane production with an estimated cost of $2,000 per hectare depending on region (Roka et al., 2009). The type of planting materials and seeding rate can influence early season cane stand population, number of millable stalk, and overall cane yield (Orgeron et al., 2007). The advantage of billet planting is to be able to plant more area in a time period with less labor. Even with the advantage, there were also several issues associated with billet planting; producers and industries observed larger crop stand problem, higher seed-cane costs and lower yield with billet planting than with whole stalk planting which prevented the full-scale adoption of billet planting in Louisiana sugarcane production systems (Hoy, et al., 2004; Benda, et al., 1978; Croft, 1998; Viator et al., 2005; Johnson, et al., 2011; Yin and Hoy, 1997; Yin and Hoy, 1998).

In 1969, 44 Louisiana sugar mills processed 5.54 million metric tons of sugarcane (Anonymous, 2009). From 1969 to 2008, 32 processers have closed sugar mill operations; however, the amount of cane processed during the 2008-2009 harvest season was 11.09 million metric tons, a 5.5 million metric ton increase compared to the 1969-1970 crop (Anonymous, 2009). The amount of cane processed over the past 39 years has increased in spite of fewer mills; this has been achieved by increasing the sugar factories' daily processing capacity and extending the harvest period. Louisiana's sugar factories begin processing sugarcane in late-September or early-October to avoid freezing temperatures. Harvest is usually completed between late-December and early-January, depending on the crop tonnage and weather conditions.

Therefore, regardless of crop age (plant cane and ratoon cane), the existing bio-refineries and raw sugar mills in Louisiana operate only three months in a year. For extended operation season, supplemental feedstock like energy cane needs to be considered besides sugarcane that can also be processed for bio-ethanol using the same equipment.

Furthermore, studies have been devoted to understanding nitrogen (N) than any other nutrient. Nitrogen is the fundamental element in chlorophyll pigments which is responsible for photosynthesis that accounts for 90% of plant dry weight production (Poorter et al., 1990). Also, N influences yield, grain quality and disease resistance in crop production. Thus, it is considered as the most limiting nutrient for plant growth and production in non-legume cropping systems. The very dynamic nature of N in the soil makes it very difficult to manage due to its wide oxidation state (-3 to +5). Therefore, utilizing methods that can more accurately determine N rate recommendations is important to maintain agronomic productivity (Wiedenfeld, 1995). Application of N fertilizer at optimum rate is essential for crop production to maximize economical return with less environmental impacts (Tubana et al., 2011; Raun et al., 2011; Lofton and Tubana, 2015; and Kanke et al., 2016). Optimal N fertilizer application rate is dependent on many factors, such as soil type, crop age, plant and soil characteristics, climate, length of growing cycle, and length of growing season (Wiedenfeld, 1995; Wood et al., 1996; Legendre et al., 2000).

The studies conducted by Legendre et al. (2004) and Viator et al. (2013) showed that excessive N content in sugarcane results in a prolonged vegetative growth period, delayed ripening, and reduce sucrose content (Legendre et al., 2004; Viator et al., 2013). Similar results was obtained by Wiedenfeld (1995) where sugarcane quality and yield were easily affected by N management, excess amount of N application decreased sugar yield, juice purity as well as recoverable sucrose. For cellulosic biofuel production, the addition of extra fertilizer may be of a benefit to get more biomass. However, the effect of the fertilizer on the composition of the stalk is not known. Mislevy et al. (1995) found only a slight benefit in energy cane (US 72-1153) biomass yield when N rate was increased from 168 to 336 kg ha^{-1}. Therefore, application of N fertilizer at the right rate, time, source, and placement are an integral part of crop production to maximize economical return as well as to minimize environmental risks.

Golden (1981) reported that sugarcane grown in Louisiana accumulated approximately 135 kg N ha^{-1} to 168 kg N ha^{-1}, depending on N rate application, throughout the growing season. Curtis and Loupe (1975) also reported that sugarcane production required 90-135 kg N ha^{-1} for most areas in Louisiana and 135-157 kg N ha^{-1} in the Red River Valley for plant cane and 135 to 157 kg N ha^{-1} for stubble cane for all areas.

In Louisiana, N fertilizer is applied only once between early April until the beginning of May. Currently, LSU AgCenter recommends N fertilization rates based on soil type and crop age. Nitrogen recommendations are between 67 to 110 kg N ha^{-1} for plant cane and from 88 to 132 kg N ha^{-1} for ratoon cane crop (Legendre et al., 2000). Although energy cane is somewhat similar to sugarcane in growth behaviors, information on the production of energy cane related to fertilization is limited. Research to date has not been enough to identify the ideal rates of fertilizer application for energy cane.

According to Raun et al. (2005), it is necessary to have an established yield prediction model in order to develop nitrogen (N) algorithm for determination of N rates that will maximize crop yield. Crop yield estimation has an important role on economic development both at a national and regional scale (Hayest and Decker, 1996; and Prasad, 2006). Conventional and remote sensing are the two methods used for yield estimation. Conventional methods (destructive biomass sampling) are often complicated, costly, time consuming, and they cannot be used in a large-scale operation (Reynolds et al., 2000). Remote sensing technology is an acquisition of information about an object or phenomenon without making physical contact with the object using sensors (satellites, air-borne, and ground-based sensors) (Lillesand et al., 2008).

Remote sensing technology has recently been investigated as a tool to predict optimum mid-season N application rates while accounting for both field spatial and temporal variability (Cao et al. 2015; Harrell et al. 2011; Tubana et al. 2008). This N rate recommendation, derived from spectral indices, has been tested and showed promise in increasing N use efficiency (NUE). Several reports have shown that vegetation indices (VIs) based on spectral reflectance can be used to accurately predict crop physiological variables, including plant biomass (Tucker, 1979), photosynthesis (Zhao et al., 2003), chlorophyll content (Tucker, 1979), plant N status (Bronson et al., 2003), and yield (Raun et al., 2002; Zhao et al., 2003).

Vegetation indices are determined with mathematical calculation using two or more wavelengths reflected from vegetation surfaces and provide some information on different crop parameters (LAI, crop cover, moisture stress, etc.). Different vegetation indices like simple ratio (SR), normalized difference vegetation index (NDVI), NDVI red-edge, and SR red-edge are commonly used to predict biomass yield (Hansen and Schjoerring, 2003; Mutanga and Skidmore, 2004; and Vina and Gitelson, 2005).

There have been reports regarding some downsides of using red wavelength in calculating VI in high biomass producing crops. Chlorophyll has a strong absorption in red wavelength 660-680 nm and after certain concentration of chlorophyll a, red light loses its sensitivity (Lorenzen and Jensen, 1988; and Yang et al., 2013). To address this problem, many studies evaluated an alternative spectral region called red-edge. Red-edge approximately refers to 680–740 nm in the electromagnetic spectrum and is the wave band between the red and NIR bands. Radiation in the red band is strongly absorbed by chlorophyll pigments whereas radiation from the NIR band is reflected based on leaf structure (Kanke et al., 2016). Energy cane produces a very high amount of biomass and thus it is imperative to identify VI that has the ability to discriminate energy cane yield biomass without getting saturated even at canopy closure.

Another aspect of remote sensing technology that were being investigated is on the application of airborne imaging spectrometer data to quantify non-pigment biochemical components of vegetation canopies which were first reported by Wessman et al. (1988) and Peterson et al. (1988). Since then, remotely sensed data from imaging spectrometers have continued to be improved and applied to quantify vegetation constituents such as water, protein, cellulose, and lignin (Card et al., 1988; Wessman et al., 1989; Matson et al., 1994; Zagolski et al., 1996; Martin & Aber, 1997; Roberts et al., 1997; Ustin et al., 1998; Serrano et al., 2002; Smith et al., 2003).

Although, energy cane has a great potential as a biomass feedstock, there are still uncertainties in producing it in a large scale. Biofuel industry structure must be evaluated to determine issues related to production (planting, fertilization, and harvesting), transportation, processing, and storage. The quality, availability and accessibility of biomass feedstock are a critical part of the biofuel industry. Understanding the crop composition and its variability during growing season, harvesting and storage are essential elements for evaluation of availability of convertible sugars and fiber. Therefore, estimating the expected crop production cost and evaluating the capital and operating cost for bio-refineries is critical to assess the competitiveness of biomass crops and justify the new crop production for the growers to support the emerging cellulosic biofuel industry in the southern USA.

In order to answer these queries, this study was conducted to evaluate how planting scheme, N rates, and harvesting date may affect on biomass accumulation, biomass quality parameters, nutrient uptake and biomass chemical composition. Also, this study aimed to evaluate the relationship between spectral reflectance and energy cane stalk yield, fiber yield (cellulose and hemicellulose) and N uptake as affected by different harvest date.

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Chapter 2. Nitrogen Rate and Harvest Date Effects on Energy Cane Yield, Quality Parameters, Nutrient Uptake and Biomass Chemical Composition

2.1 Introduction

Sugarcane (*Saccharum* sp. hybrid) production has been cultivated in the southern parts of Louisiana since 1795. Sugarcane is bred for large stalk diameter, low fiber, and high sugar content (Gravois, 2001). With the “oil shocks” of 1973 and 1979 along with price increases that led to economic disruption at international, national, and local levels greater emphasis was placed on the development of energy cane (*Saccharum* spp.) (Baldwin et al., 2012). A joint study by U.S. Department of Energy and U.S. Department of Agriculture published in 2005 estimated the potential of biomass as a feedstock for bioenergy industry. Furthermore, they projected that the United States can produce nearly one billion dry tons of biomass annually while still continues to meet the demand on food, feed and export (Perlack et al., 2005). The passing of Energy Independence and Security Act of 2007 (EISA) set the stage for a resurgence of all biomass crops, including energy cane. In this legislation, the Renewable Fuels Standard set forth goals for domestic renewable fuel production: 34 billion liters of renewable fuel production in 2008, rising to 136 billion liters by 2022, with 79 billion liters required to be produced from cellulosic ethanol and other advanced biofuels (Congressional Research Service, 2007). Cellulosic ethanol refers to ethanol derived from cellulose and hemicellulose from biomass. Other advanced biofuels would include ethanol derived from waste material, biomass-based diesel, biogas, and butanol and other alcohols produced through conversion of organic matter from renewable biomass (Salassi et al., 2014).

In 2007, Louisiana State University released L79-1002, a cane used specifically as a biomass feedstock (Bischoff et al., 2008). However, as prices of the fuel decreased, the interest of using biomass feedstock crop faded away. Because energy cane was bred for high biomass and fiber content there was a proportional reduction in sugar concentration, making it less attractive to the sugar industry.

Increasing uncertainty of petroleum supplies due to rising demand, decline in known reserves, and concerns over climate change and greenhouse gas emissions associated with fossil fuels usage has led to various government programs promoting biofuels as a sustainable option to overcome these issues (Saini et al., 2014). According to Fulton et al. (2004), bioethanol can reduce greenhouse gas emissions by approximately 30–85 % compared to gasoline, depending on the feedstock used. Worldwide increasing interest in the production of bioethanol is exemplified by production of 85 billion liters of bioethanol in 2011 (Singh and Bishnoi, 2012; Avci et al., 2013).

With the renewed interest in non-conventional fuel from bio-renewable sources including lignocellulosic material, energy cane has gained much attention due to its low production cost requirement and high biomass yield potential to sustain a large-scale biomass supply (Kim and Dale, 2005). Energy cane has been identified as a crop with having significant potential to be developed as a biofuel feedstock that can contribute more efficiently to biofuel production, especially not competing with food production (which depends on the region of the world or country that is considered), and can provide significant energy gain if considered in all input-output equation (Hill et al., 2006; Johnson et al., 2007; Coombs, 1984; Gonzales-Hernadez et al., 2009; Macedo, 1998; Schmer et al., 2008; Yuan et al., 2008).

Aside from the high biomass tonnage characteristic of energy cane, the existing infrastructure and equipment that supports Louisiana's $2 billion sugarcane industry could be directly applied to production of energy cane (Baldwin et al., 2012). Also, Louisiana has a favorable climate for production of a wide variety of energy crops for biofuel production, with an average temperature of 19°C, precipitation of 163 cm per year, and a long growing season ranging from 230 to 290 days. Fertile organic soil, sub-tropical climate, adequate rainfall, and high growing-degree days led to the oldest and largest commercial sugar cane industry in the U.S (Kim and Day, 2011).

Studies have been devoted to understanding nitrogen (N) utilization by crops than any other nutrient. It is the most limiting nutrient in non-legume cropping systems and the least predictable due to its very dynamic nature. When N fertilizer is applied in the soil it will undergo several processes and can easily be lost in the soil system. Application of N fertilizer at the optimum rate is an integral part of crop production to maximize economical return as well as to minimize environmental risks (Tubana et al., 2011; Raun et al., 2011; Lofton and Tubana, 2015; and Kanke et al., 2016).

It should be noted that energy cane, like sugarcane is a semi-perennial that is vegetatively propagated which can be harvested annually up to five years without replanting; the first harvested crop is termed plant cane and ratoon cane for each successive harvest. In Louisiana, N fertilizer is applied only once in every cropping season and usually done in early April until the beginning of May when sugarcane grows. Currently, LSU AgCenter N rate recommendation is based on soil type and crop age. Nitrogen recommendations are between 67 to 110 kg N ha^{-1} for plant cane and from 88 to 132 kg N ha^{-1} for ratoon cane crop (Legendre et al., 2000). A study conducted by Wiedenfeld (1995) showed that sugarcane quality and yield are easily affected by N management; excess amount of N application decreased sugar yield, juice purity as well as recoverable sucrose.

Although energy cane is considered sugarcane, information on the production of energy cane is limited. Research to date has not identified the ideal rates of fertilizer application for energy cane. For cellulosic biofuel production, the addition of extra fertilizer may be of a benefit to get more biomass. However, the effect of the added fertilizer on the composition of the stalk is not known. Mislevy et al. (1995) found only a slight benefit in biomass yield when N rate was increased from 168 to 336 kg ha^{-1}.

The existing harvesting scheme of cane takes place only in three months in a year (October to December) regardless of crop age (plant cane and ratoon cane). Thus, in turn, the sugar mills also operate within the period simultaneously with harvesting. Supplying energy cane as feedstock outside this period has agronomic and economic advantage for the biofuel industry. To answer these queries, this study was conducted to determine the N application rate to optimize energy cane production and to evaluate if different N rates and harvesting energy cane one- and two-months earlier than the scheduled harvest date affects its quality parameters, yield, nutrient uptake and biomass chemical composition.

2.2 Materials and Methods

2.2.1 Site location, experimental design and layout

This study was established at the Louisiana State University AgCenter Sugar Research Station in St. Gabriel, Louisiana (30º15'47"N 91º05'54"W) on a Commerce silt loam soil (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent). Before planting, composite soil samples (16 cores per quadrant) were randomly collected for initial soil chemical analysis. The samples were dried, ground, and extracted with Mehlich-3 solution (Mehlich, 1984) to determine multi-element concentration. Carbon:nitrogen (C:N) ratio was determined using CN 91 analyzer (Model: Vario el cube; Manufacturer: Elementar). The soil had an initial pH value of 5.5 with C:N ratio of 6:1, and phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), and copper (Cu) content of 34, 170, 458, 10.8, and 3.5 mg kg^{-1}, respectively.

The plot size was 9 m by 1.83 m containing three bedded rows. The length of the alley between plots was 3 m. The treatments included two energy cane varieties, Ho 02-113 and US 72-114. Variety Ho 02-113 is a cane variety with high fiber and low sucrose content that can be used as a feedstock for the production of biofuels. The female parent of Ho 02-113 is SES 234 (*Saccharum spontaneum*), and the male parent is LCP 85-384, a commercial sugarcane variety. It has an extremely high population of small diameter stalks. The canopy is very erect, and the variety has excellent vigor and stubbling ability. Variety US 72-114 is also a high fiber and low sugar content cane variety and has been tested for high biomass production for biofuel. The female parent of US 72-114 is CP52-068 and the male parent is US66-65-11. The four N application rates were 0, 56, 112, and 224 kg ha^{-1}. A 2 x 4 factorial treatment structure was laid-out using split plot in randomized complete block design where variety was designated as the main plot and N application rate as sub-plot and was replicated four times.

2.2.2 Planting, fertilization, harvesting, and plant analysis

Planting was done on September 14, 2012 using billets as planting material. Billets were cut with a combine harvester with an average of 50-55 cm in length with approximately three buds per billet. Bedded rows with 1.8 m were opened wherein 5 to 6 running billets were placed. Beds were then closed and packed with approximately 6 cm of soils with a custom roller packer. In April, urea-ammonium nitrate (UAN; 32-0-0) solution at rates of 0, 56, 112, and 224 kg N ha^{-1} was knifed-in near the shoulder of each bed at 15 cm depth. The amount of K was 60-80 kg ha^{-1} and no P was applied.

The harvesting for the three dates (two- and one-month earlier, and at scheduled harvest) was done by cutting fifteen randomly selected plant from the base from the middle row of each plot. Table 2.1 shows the harvest schedule at St. Gabriel, Louisiana from 2013 to 2015 cropping year. The collected plants were partitioned into stalks and leaves and weighed separately. The stalks were shredded and analyzed for sugar quality parameters using SpectraCane Near Infrared System (Bruker Coporation, Billerica, Massachusetts) to determine theoretical recoverable sugars (TRS), sucrose content, total soluble solids (Brix), and fiber content. Following this analysis shredded material were dried at 60°C for 48 hours, ground to pass a 1-mm sieve, and analyzed for total N using CN 91 analyzer (Model: Vario el cube; Manufacturer: Elementar), elemental composition by nitric acid-hydrogen peroxide digestion procedure followed by Inductively Coupled Plasma (ICP) - Optical Emission Spectroscopy (OES). For this study, the nutrient uptake was computed as = [nutrient concentration x stalk dry weight]. Lignocellulosic composition was determined using ANKOM^{2000} Filter Bag method. Ground stalk samples weighing 0.5 g was placed in ANKOM F57 filter bags and heat sealed and underwent a series of extractions for Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL). The residue after NDF extraction is predominantly composed of hemicellulose, cellulose and lignin while the ADF extraction is composed of cellulose and lignin and ADL residue represents lignin. The different lignocellulosic composition was computed using difference method:

% Hemicellulose = % NDF – % ADF;

% Cellulose = % ADF – % ADL; and

% Lignin = % ADL

At scheduled harvest, after taking 15 plants from the middle row cane stalks were cut from each plot using a Case IH 8800 Series single row chopper (Case IH Agriculture, Racine, WI) and loaded to wagon with load cell to determine the plot weight.

Table 2.1. Harvest schedule of the cane stalks at St. Gabriel, Louisiana from 2013 to 2015 cropping seasons.

Harvest Dates	**2013** **Plant Cane**	**2014** **First Ratoon**	**2015** **Second Ratoon**
2-Months Earlier	October	September	August
1-Month Earlier	November	October	September
Scheduled Harvest	December	November	October

2.2.3. Data Analysis

Statistical analysis was done using SAS 9.4 software (SAS Institute, 2012). Analysis of variance (ANOVA) was performed to evaluate the effects of variety, N rate, harvest dates, and their interactions on millable stalk yield, nutrient concentration and uptake, and fiber composition. Mean separation was done by Tukey–Kramer post-hoc test for any significant effect at $p<0.05$.

2.3 Results and Discussions

2.3.1 Climatic Condition

Monthly average temperature and precipitation for 2013 to 2015 are presented in Figure 2.1. The average monthly precipitation (~7.5 mm) was similar for 2013 and2014 wherein most of the rain was received in the months of February, May, and August. However, for 2015 rainfall was high in the months of June, October, and November (~8.0 mm). In terms of total rainfall per year, 2013 and 2015 received similar amount of rainfall with a total both around 1700 mm while it was only 1430 mm in 2014. The average monthly temperature was very similar across years; the highest temperature (25°C) was recorded in the months of June, July, and August. According to Richard and Anderson (2014), dry conditions and sunlight promote tillering at the beginning of each growing season, whereas frequent rainfall and cloudy conditions discourage excessive tillering. The grand growth period that may last 140-196 days is responsible for cane biomass accumulation and during this period rainfall or irrigation is critical to sustain this growth rate (Woodard and Prine, 1993).

2.3.2 Millable Stalk and Leaf Yield

Partitioning of whole plants into leaves and stalk was done in this study in order to estimate the amount of residue produced from energy cane. The results of this study showed no interaction effect between N rate x variety, N rate x harvest date, and N rate x variety x harvest date on both stalk and leaf yields. Furthermore, the results showed that variety and N rate had no effect on the dry stalk and leaf yields for the three cropping years (2013 to 2015) (Table 2.2). Although, N fertilization increased the stalk and leaf yields of energy cane, this was not significantly different ($p<0.05$) from the unfertilized plot. There was an evident reduction in dry stalk yield from plant cane to ratoon cane (9 Mg ha^{-1}) while dry mass yield of the leaf increased at second ratoon crop (47 Mg ha^{-1}). Viator et al. (2010) also showed that the stalk yields tend to decrease with each yearly harvest of a crop cycle, especially when mechanically harvested in the temperate climate. The trash dry matter of energy cane in our study was four times higher than those observed by Franco et al. (2013) for sugarcane in which the average trash dry matter yield was 10.7 Mg ha^{-1}. Such high biomass yield of energy cane makes it a good source of feedstocks for biofuel production. The usually high amount of leaf biomass produced during second ratoon cropping might partly be due to high amount of rainfall received by cane during the grand growth and maturity (and ripening) stages.

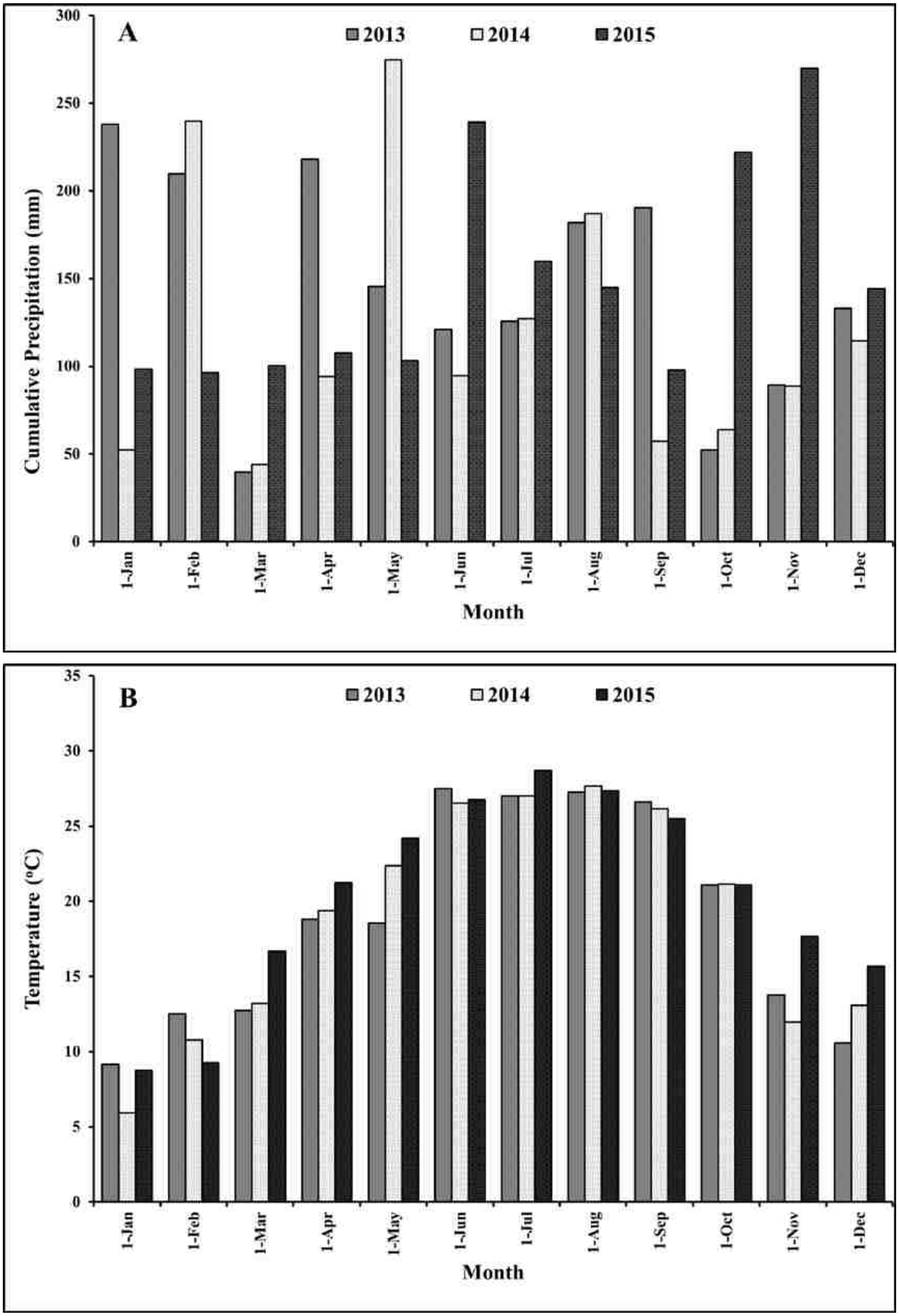


Figure 2.1. Monthly cumulative precipitation (A) and average temperature (B) in St. Gabriel, Louisiana for 2013, 2014, and 2015.

Table 2.2. The effect of variety, nitrogen rate, and harvest date on stalk and leaf dry yield of energy cane at St. Gabriel, LA 2013-2015. Results of analysis of variance for each of the factors and their interaction are also presented.

	Stalk Dry Yield (Mg ha^{-1})			Leaf Dry Yield (Mg ha^{-1})		
Treatment	2013 Plant Cane	2014 First Ratoon	2015 Second Ratoon	2013 Plant Cane	2014 First Ratoon	2015 Second Ratoon
Variety						
Ho 02-113	32.4	21.0	20.0	14.1	12.7	48.8
US 72-114	24.6	18.3	19.3	12.3	15.4	71.1
N Rate kg ha^{-1}						
0	25.2	16.5	14.9	14.6	14.5	53.1
56	26.0	19.0	18.6	10.7	13.1	62.0
112	30.8	21.0	22.4	15.3	15.2	65.1
224	32.0	22.0	22.8	12.3	13.4	59.6
Harvest Date						
Two-Months Earlier	28.4a†	16.7b	13.6c	15.4a	11.8b	57.4b
One-Month Earlier	29.4a†	20.3a	21.2b	13.2ab	13.6b	64.3a
Scheduled Harvest	27.6a†	21.8a	24.3a	11.0b	16.8a	58.2b
Variety	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS
Harvest Date	NS	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS
Variety*N Rate* Harvest Date	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

On the other hand, harvest date had a significant effect ($p<0.05$) on both dry stalk and leaf yield (Table 2.2). The scheduled harvest i.e., harvesting of 2nd ratoon, 1st ratoon, and plant cane in October, November, and December, respectively consistently obtained the highest stalk yield for the three cropping years with an average yield of 25 Mg ha^{-1}. The effect of harvest date on dry mass leaf yield was not consistent. Similar studies conducted by Mislevy et al. (1995) with energy cane and *Erianthus* also revealed that harvesting at the maturity stage in October or December generally results in highest dry biomass yields. Furthermore, they found that the percentage of green leaves decreased from 70% when harvested in October to 17% when harvested in December, with green leaves only being at the top of the stalk for the December harvest. At the later harvest, an additional 17–20% of leaves dry mass was recorded.

According to Richard et al. (1995), the length of the growing season dictates biomass yields. In tropical climate, the harvest season can extend over a nearly 12-month period due to minimal fluctuation of temperature while in temperate climate the growing season may only be 7–10 months in length. Several studies conducted, stating that most tall grasses, including energy cane, will not tolerate continuous harvesting at an immature stage without sacrificing yield in the subsequent ratoon crop (Woodard and Prine, 1993; Viator et al., 2010; Mislevy et al., 1995; Mislevy and Fluck, 1992; Mislevy et al., 1992; Mislevy et al., 1997).

2.3.3 Energy Cane Quality Parameters

The energy cane quality parameters (TRS, brix, and sucrose content) were significantly different ($p<0.05$) for three harvest dates (Table 2.3). It is evident that the lowest TRS, brix, and sucrose contents was observed in energy cane harvested two months earlier whereas the highest values were obtained from cane harvested at the scheduled dates, respectively. As much as 86 kg Mg^{-1} reduction in TRS was observed for cane harvested two months earlier than the scheduled harvest.

According to Mislevy et al. (1995 and 1997), harvest date affects both the quantity and the quality components of the millable stalk. Early harvest, although necessary in temperate environments where sucrose crystallization is a target, has negative impacts on sugarcane productivity such as lower biomass yields, higher stalk moisture contents, and reduced stubble longevity (Viator et al., 2010). Legendre (1975) also reported that sucrose levels are lowest in late-September but significantly increases as the season progresses, with highest levels occurring in December. His finding is similar to our study wherein sucrose content were highest in the months of November and December (10%) while lowest in the months of August and September (5-6%). Factors that affect the maturation and sucrose accumulation of the sugarcane stem include crop age, N status, moisture, and temperature (Bull, 2000; Tubana et al., 2007).

Among the measured quality parameters, only the TRS content was significantly affected ($p<0.05$) by variety and N rate. The Ho 02-113 cane variety had higher TRS than US 72-114; a difference of 23 kg Mg^{-1} for plant cane crop (2013) and second ratoon crop (2015). Furthermore, the amount of TRS was significantly higher with no application of N fertilizer (0 N) compared with the N treated plots (56, 112, and 224 kg N per hectare). The average amount of TRS for the three cropping years was 112 kg Mg^{-1} under 0 N and decreased to 73 kg Mg^{-1} with the application of 224 kg N ha^{-1}.

Table 2.3. The effect of variety, nitrogen rate, and harvest date on TRS, BRIX, and sucrose content of energy cane at St. Gabriel, LA 2013-2015. Results of analysis of variance for each of the factors and their interaction are also presented.

	TRS (kg Mg^{-1})			**BRIX (%)**			**Sucrose (%)**		
Treatment	2013 Plant Cane	2014 First Ratoon	2015 Second Ratoon	2013 Plant Cane	2014 First Ratoon	2015 Second Ratoon	2013 Plant Cane	2014 First Ratoon	2015 Second Ratoon
Variety									
Ho 02-113	127a	87a†	92a	12a†	14a†	13a†	10a†	8a†	8a†
US 72-114	105b	78a†	68b	15a†	14a†	12a†	8a†	8a†	7a†
N Rate kg ha^{-1}									
0	126a	106a	103a	13a†	15a†	13a†	9a†	9a†	9a†
56	123a	71b	91b	14a†	14a†	13a†	9a†	8a†	8a†
112	119a	84ab	69c	13a†	13a†	12a†	9a†	8a†	9a†
224	95b	69b	57d	13a†	13a†	12a†	8a†	7a†	6a†
Harvest Date									
Two-Months Earlier	107b	49c	40c	14b	13c	10c	9b	6c	5c
One-Month Earlier	124a	75b	73b	15a	14b	13b	8c	8b	7b
Scheduled Harvest	No data	122a	126a	11c	15a	15a	10a	10a	10a
Variety	*	NS	*	NS	NS	NS	NS	NS	NS
N Rate	*	*	*	NS	NS	NS	NS	NS	NS
Harvest Date	*	*	*	*	*	*	*	*	*
Variety*N Rate	*	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	*	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate* Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey's post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Our results conformed to the study of Lofton and Tubana (2015) wherein the sugarcane quality parameters were significantly affected by N rate. Similar result was also found by Muchow et al. (1996); they reported that there was a significant decrease in recoverable sugars with increasing N rate and reported that this was associated with a decrease in sugar content in stalk dry matter. Another possible reason for the reduction of TRS might be due to higher cane biomass in the N treated plots compared with the zero N rate plots. The production of biomass in cane can be examined in terms of the capture and utilization of solar radiation; increased N supply also increased both the capture and utilization of radiation whilst decreased the sugar concentration in dry millable stalks (Muchow et al., 1996). Orgeron (2012) also evaluated the effect of N fertilizer rates of 67,112, and 157 kg ha^{-1} on stalk weight, percent fiber, sugarcane yield, TRS, and sugar yield; the outcome showed that the N rate of 67 kg ha^{-1} was as effective as the 157 kg ha^{-1}.

Moreover, variety and N rate did not influence the fiber content of energy cane but showed a significant difference with harvest date in three cropping years. Scheduled harvest date obtained the highest amount (>30%) of fiber, which was very evident in 2013 plant cane (Figure 2.2). However the amount of fiber declined with the succeeding crop years (2014 and 2015). The preliminary results in the introgression program conducted by Cana Vialis (a Monsanto group of Company) showed that selected F1 clones (cross between a commercial hybrid and *S. spontaneum*) had number of stalks per linear meter that ranged from 35 to 40 and fiber content

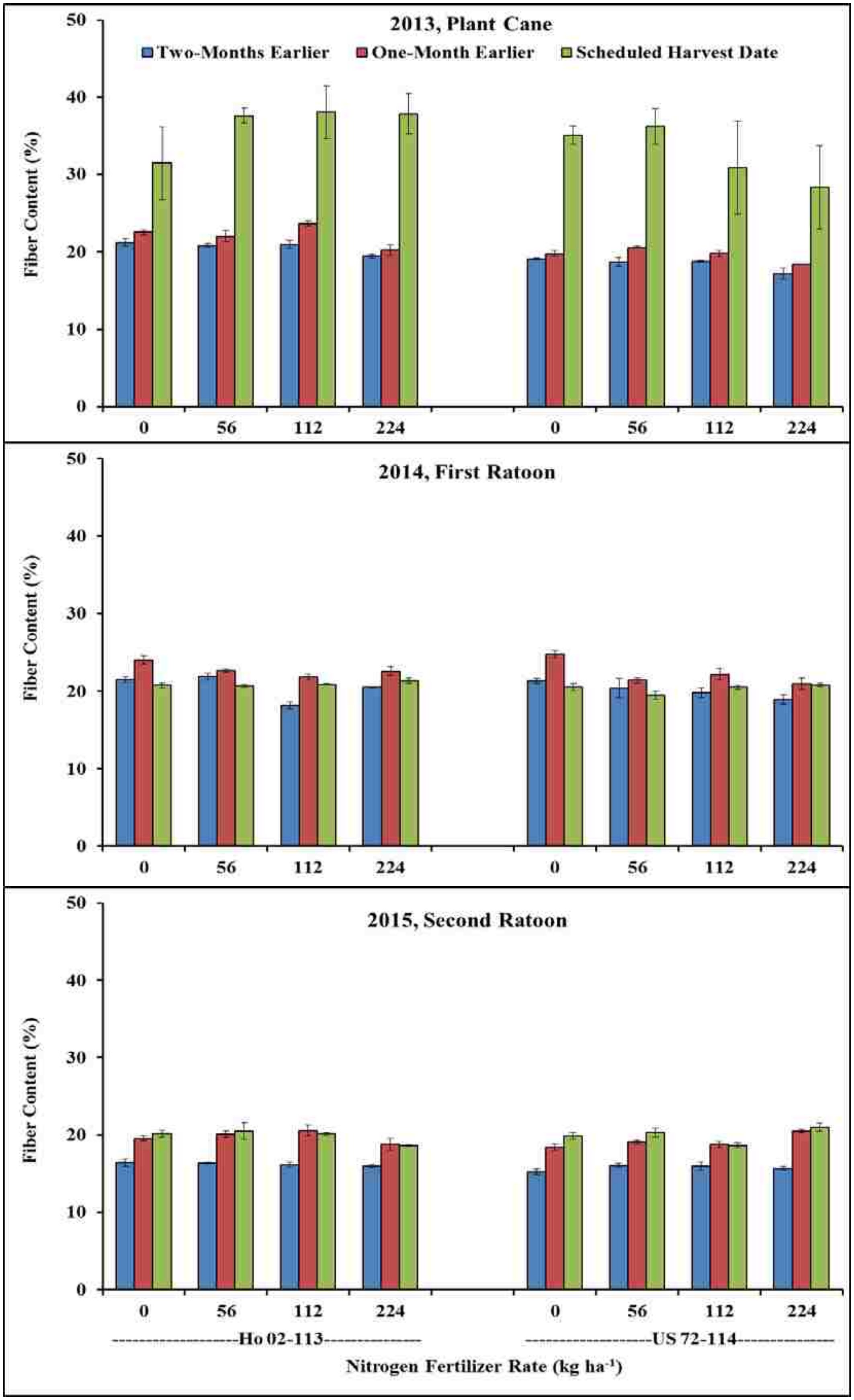


Figure 2.2. Nitrogen rate and harvest date effects on fiber content (%) of energy cane at St. Gabriel, LA from 2013-2015.

ranging from 15.4 to 19.9% compared with the 12% of the commercial variety (Matsuoka et al., 2012). Furthermore, the stalks productivity ranged from 155 to 236 metric tons against 148 metric tons of commercial variety, and the productivity of fiber ranged from 30.6 to 40.2 metric ton.

With the quest to produce second generation fuels from cellulosic biomass these early generations F1 hybrids (energy cane) are ideal bio-feedstock candidates. Most of these hybrids can produce dry matter yields of 30 Mg ha^{-1} annually over four fall harvests, with about 20 Mg ha^{-1} being fiber and 10 Mg ha^{-1} being Brix (Anonymous, 2007). According to Richard et al. (2014) the sugar and fiber levels in the harvested cane stalks are generally dependent on the length of the growing season, amount of extraneous matter present, and the harvesting conditions.

2.3.4 Lignocellulosic Composition

The lignocellulosic components of energy cane stalk (unpressed) and leaves were not significantly affected by variety and N application but were influenced by different harvest dates (Figures 2.3, 2.4, and 2.5). For 2013, there was an evident reduction in cellulose and hemicellulose content of leaves with harvests from two months earlier to scheduled harvest except for lignin. However for the stalk, the content was increasing with harvest date for hemicellulose and cellulose but not for lignin. For the ratoon crops in 2014 and 2015, these trends were not evident and not consistent with what was observed in 2013. Cell walls are the major component of plant biomass and consist mainly of three organic compounds: cellulose, hemicellulose, and lignin. These compounds are also the major components of natural lignocellulosic materials (Yang, 2001). The composition of cell walls varies widely among species (Popper et al., 2011) and may vary within an individual, depending on the cell type or in response to environmental conditions (Knox, 2008). According to Tarchevsky and Marchenko (1991), the seasonal changes in content of structural polysaccharides cause the alteration of the ratio of the mass of leaves to that of the stems. Leaves of tropical cereals (*Panicoideae* and *Eragrostideae*) are richer in cellulose than those in moderate climate (*Festuciformis*). Furthermore, the monosaccharide composition of hemicellulose of *Panicoideae* and *Eragrostideae* differs from that of *Festuciformi* wherein glucose being the main component in the former and xylose in the latter.

For 2013 plant cane, the stalk of energy cane at scheduled harvest obtained the highest amount of hemicellulose (19%) and cellulose (34%) and the lowest in lignin (21%) content (Figure 2.3). On the other hand, the leaves of energy cane harvested one and two months earlier obtained the highest hemicellulose (27%) and cellulose (31%) content. For 2014 first ratoon crop, the amount of hemicellulose (37%) and cellulose (30%) of cane stalk was higher at one month earlier harvesting while for the leaves, high amount of hemicellulose (27%), cellulose (31%), and lignin (19%) were observed at scheduled harvest. Also, no significant difference was observed for hemicellulose content (Figure 2.4).

For 2015 second ratoon cane crop, the hemicellulose was high 35% and 39% at scheduled harvest for stalk and leaves, respectively (Figure 2.5). However, cellulose was high at one- and two- months earlier harvest dates (~31%). Lignin was not affected by harvest date for stalk but for the leaves, the scheduled harvest obtained the highest lignin content (19%). The result of this study demonstrated higher hemicellulose composition for both stalk and leaves for the ratoon crops (>30%) compared with the plant cane crop (<20%). However when combined across crop age, the stalk and leaves had similar composition of 28.5, 29, and 20.5% for hemicellulose, cellulose and lignin, respectively.

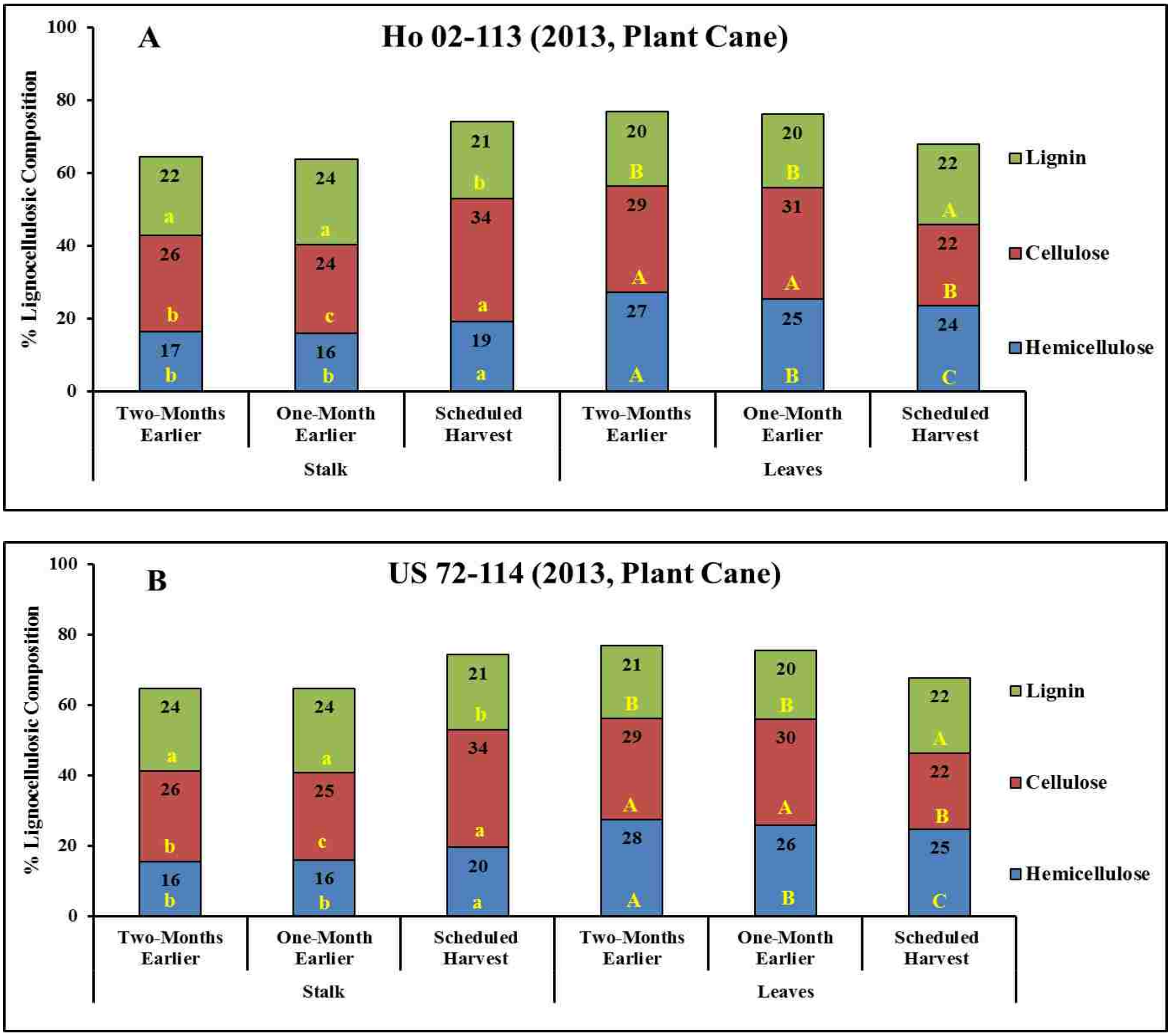


Figure 2.3. Nitrogen rate and harvest date effects on lignocellulosic composition (%) of energy cane stalk and leaves of Ho 02-113 (A) and US 72-1144 (B) for 2013 (plant cane) at St. Gabriel, LA. For each lignocellulosic component, values with same lowercase (stalk) and uppercase letter (leaves) are not significantly different at $P = 0.05$.

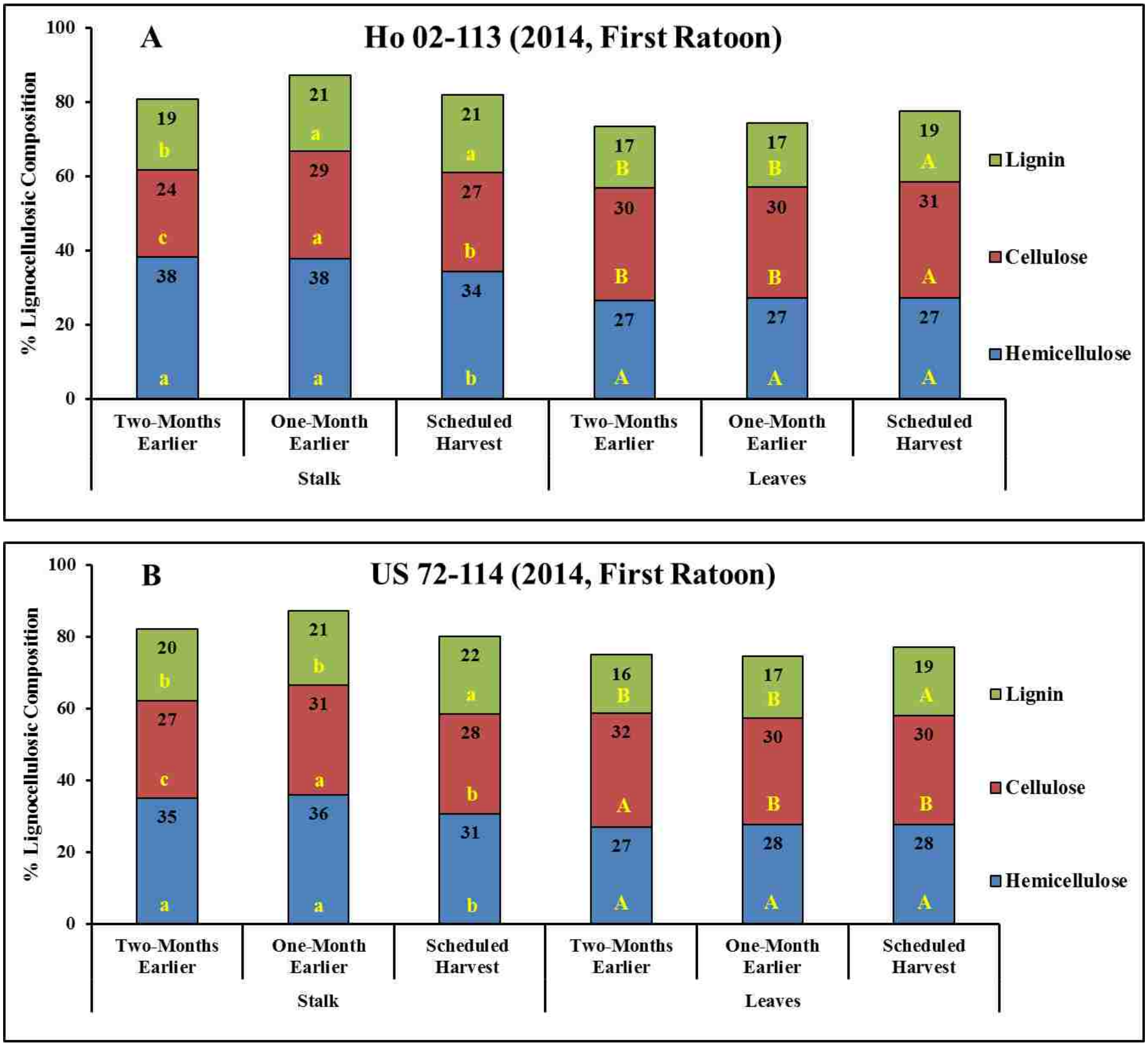
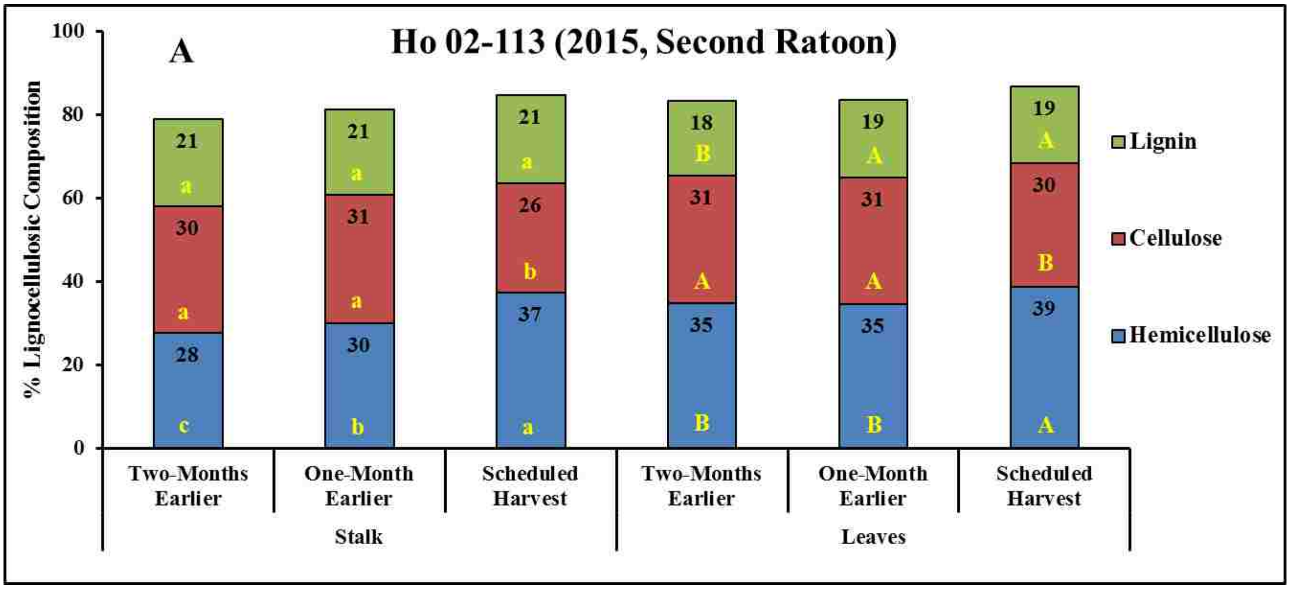


Figure 2.4. Nitrogen rate and harvest date effects on lignocellulosic composition (%) of energy cane stalk and leaves of Ho 02-113 (A) and US 72-114 (B) for 2014 (first ratoon) at St. Gabriel, LA. For each lignocellulosic component, values with same lowercase (stalk) and uppercase letter (leaves) are not significantly different at $P = 0.05$.



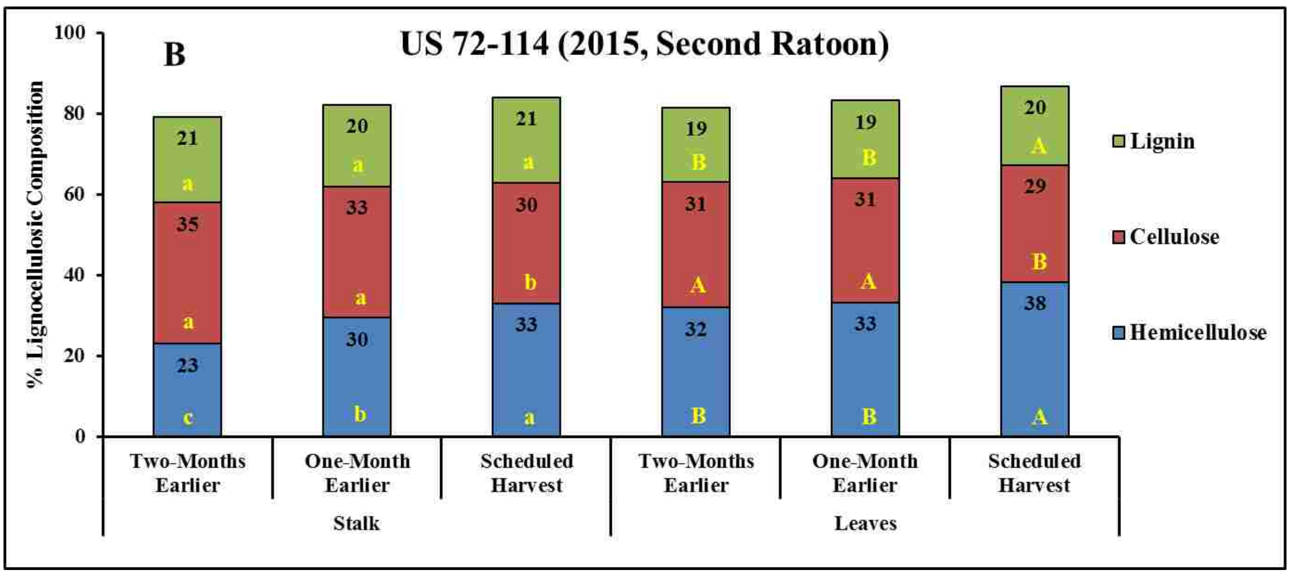


Figure 2.5. Nitrogen rate and harvest date effects on lignocellulosic composition (%) of energy cane stalk and leaves of Ho 02-113 (A) and US 72-114 (B) for 2015 (second ratoon) at St. Gabriel, LA. For each lignocellulosic component, values with same lowercase (stalk) and uppercase letter (leaves) are not significantly different at $P = 0.05$.

The study conducted by Ogata (2013) showed the cellulose composition of energy cane varied from 26% to 54% (average of 44%), while hemicellulose varied from 16% to 26% (average of 22%) and lignin content ranged from 17% to 27% (average of 24%). Kim and Day (2011) also reported that chemical composition of sugarcane bagasse was determined to be 42% cellulose, 25% hemicellulose, and 20% lignin while the energy cane lignocellulosic composition was 43% cellulose, 24% hemicellulose, and 22% lignin. The bagasse fraction in commercial sugar varieties consists of 38% cellulose, 19% hemicellulose, 22% lignin, 4% protein, and 3% ash, with the remaining 14% consisting of sugar, soil from harvesting, and other types of solids (Legendre and Burner, 1995; Baoder and Barrier, 1998). According to Burner (2009) leaves represented as much as one third of the biomass and had large cellulose (≤482 g kg^{-1}) and lignin (167 g kg^{-1}) concentrations. Burner et al. (2009) suggested that delaying harvest beyond a freeze in more temperate climates could improve feedstock quality for cellulosic conversion by reducing water concentrations, but this could also reduce the yield of leaves, lignin, ash, and cellulose.

2.3.5 Nutrient Concentration and Uptake

The macro- and micro- nutrients concentration and uptake of energy cane stalk and leaves for three cropping years are presented in Tables 2.4 to 3.15. Overall, harvest date significantly influenced the nutrient concentration and uptake of energy cane stalk and leaves but not by variety and N rate. Significant difference was observed for P, K, Cu and Zn uptake of the stalk while significant difference was observed for N, K, Ca, Mg, Fe, and Mn uptake of the leaves for the three cropping seasons (2013, 2014, and 2015).

Furthermore, the results from this study demonstrated that concentration of macro- and micro- nutrients of energy cane stalk and leaves significantly decreased from two months earlier harvesting towards scheduled harvest date for the three cropping seasons (2013, 2014, and 2015). However, the nutrient uptake (macro and micro) was increasing towards scheduled harvesting except for 2013 plant cane. The uptake of N, P, K, Ca, Mg, and S in the stalk ranged from 54-73, 29-38, 148-257, 16-27, 10-15, and 12-32 kg ha^{-1}, respectively. The uptake of N, P, K, Ca, Mg, and S in the leaves ranged from 108-130, 11-30, 108-192, 16-67, 17-56, and 15-17 kg ha^{-1}, respectively. Leite et al. (2016), found similar trend in the amount of N, P, and K in the sugarcane stalks which ranged from 32-168, 5-57, and 26-713 kg ha^{-1}, respectively. However, the amounts of N, P, and K in the dry leaves were higher in our study compared with what was reported by Leite et al. (2016) which ranged from 19-77, 0.6-4.9, and 2-96 kg ha^{-1}, respectively. Nevertheless, both studies showed that N and K constitute the largest fractions in the stalk and leaves dry matter.

It was also evident that the N concentration and uptake of the leaves was twice higher than that of the stalk particularly for the first and second ratoon crops. The average amount of N uptake of the leaves were 86, 111, and 189 kg ha^{-1} and 57, 60, and 64 kg ha^{-1} for stalk N uptake for plant cane, first ratoon, and second ratoon crops, respectively. The leaf: stem ratio generally decreases as crop biomass increases (Lemaire and Chartier, 1992; Belanger and McQueen, 1999; Belanger and Richards, 2000). This means that progressively greater proportion of C and N are allocated to the stem over the crop developmental period. In lucerne (Lemaire and Chartier, 1992) and reproductive ryegrass (Gastal, unpublished data), the decrease in leaf: stem ratio over the growth period was accompanied by a much larger decrease in N concentration of stems than the limited decrease in N concentration of laminas. According to Gastal and Lemaire (2002), N uptake of field crops is highly variable within a single year, between years, between sites, and between crops, even when the N supplies from the soil and additional fertilizer inputs are plentiful. Under ample soil N availability, crop N accumulation is highly related to crop growth rate and biomass accumulation. The amount of N taken up by the crop has a major impact on overall crop growth rate. The dependence of crop growth on crop N relies on several processes: leaf photosynthesis–N relationships, the distribution of N between leaves, leaf expansion and positioning and subsequent impacts on light interception (Novoa and Loomis, 1981; Sinclair and Shiraiwa, 1993).

Aside from N, K was also taken up by energy cane in large quantity for both stalk and leaves. The amount of K uptake for stalk ranges from 148-257 kg ha^{-1} while for leaves it ranges from 108-192 kg ha^{-1}. Also, K was taken up in larger amount at ratoon cane crops than at plant cane crop with an average of 323 kg ha^{-1} and 263 kg ha^{-1}, respectively. Our result showed similar trend with Korndörfer and Oliveira (2005) study on sugarcane wherein K was taken up in large quantity, mainly during ratoon (stubble) cropping. In addition, low levels of available K in the soil contribute to reduce sugarcane longevity (Schultz et al., 2010) therefore, is considered an important element in restoring the productivity of sugarcane ratoon (Weber et al., 2002). According to Coelho and Verlengia (1973), approximately 50% of total K absorbed during the vegetative phase of the plant between 5- and 9-months of age with a strong influence by the amount of rain and soil conditions. It was also well-documented that over-application of K decreases cane quality (Anderson and Bowen, 1990) and causes a reduction in the recovery of raw and refined sugar (Clarke, 1981) due to elevated levels of ash in sugarcane juice (Leverington et al., 1965; Kingston, 1982; and Kingston, 2014).

Moreover, our study showed higher amount of Ca in the leaves than in the stalk which is evident for the ratoon cane crops. The amount for leaves and stalk ranges from 45-58 kg ha^{-1} and 14-18 kg ha^{-1}, respectively. The same results were reported by Monti et al. (2008), where Ca was mostly concentrated in leaves, while K was equally distributed between leaves and stalk of Micanthus. Reumerman and Van de Berg (2002) also reported that leaves of miscanthus had highest Ca/K ratios which contributed to a lower slagging tendency. Thus, biofuels containing high Ca and low K, should be better suited to energy end-use.

The lack of N rate impact on nutrient concentration and uptake might be due to N from rainfall, residual soil N levels, and N turnover from the decomposition of residues remaining on the surface of the soil. The combined amount of N from these sources perhaps was enough to meet the N demand of cane and not to cause impairment in absorption and assimilation of other plant-essential nutrients.. A study conducted by Calcino et al. (2000) showed that a typical green-cane trash-blanket (GCTB) contains the equivalent of 6–14 Mg ha^{-1} of dry matter. A hectare residue layer contains 3000 to 6500 kg C, 50–100 kg N, 5–10 kg P, 30–90 kg K, 30–50 kg Ca, 15–25 kg Mg, and 8–11 kg S. Smaller amounts of micronutrients are also contained in the green trash-blanket. The plant requirement for micronutrients is small and with proper pH, sufficient amount can be recycled from the decomposition of cane residues.

Table 2.4. The effect of variety, nitrogen rate, and harvest date on macronutrient content of energy cane, plant cane (2013) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	---g kg^{-1} DM---											
Variety												
Ho 02-113	1.6	6.5	1.2	0.7	5.8	5.9	0.8	3.3	0.4	1.0	0.8	0.9
US 72-114	2.3	6.4	1.3	0.7	6.9	6.3	1.3	3.5	0.6	1.0	0.9	1.1
N Rate kg ha^{-1}												
0	1.6	6.2	1.3	0.7	6.7	5.9	1.2	3.0	0.5	0.8	0.9	1.0
56	1.7	5.8	1.2	0.6	6.1	5.8	0.8	3.2	0.4	0.9	0.9	0.9
112	1.8	6.4	1.2	0.6	6.1	5.9	1.2	3.6	0.6	1.0	0.9	1.0
224	2.9	7.5	1.2	0.7	6.4	6.9	1.0	4.0	0.5	1.2	0.9	1.0
Harvest Date												
Two-Months Earlier	1.9a†	7.0a	1.3a	0.8a	9.0a	7.6a	1.0a†	3.6a	0.5b	1.0a	1.1a	1.1a
One-Month Earlier	2.1a†	6.5ab	1.4a	0.7b	4.2c	6.3b	1.1a†	3.5a	0.7a	1.0a	0.7b	1.0b
Scheduled Harvest	1.9a†	5.8b	0.9b	0.6c	5.8b	4.5c	1.0a†	3.2b	0.4b	0.9b	0.7b	0.8c
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	NS	*	*	*	*	*	*	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate* Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.5. The effect of variety, nitrogen rate, and harvest date on macronutrient uptake of energy cane, plant cane (2013) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	N		P		K		Ca		Mg		S	
	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf
	--------kg ha^{-1} DM--------											
Variety												
Ho 02-113	46	98	33	9.8	170	90	21	14	12	50	23	13
US 72-114	67	73	37	7.6	192	74	38	12	18	41	27	13
N Rate kg ha^{-1}												
0	38	87	31	9.5	162	84	28	12	12	42	23	14
56	48	84	35	8.7	167	85	24	12	13	46	24	13
112	58	73	38	7.2	203	66	39	11	20	41	29	11
224	83	99	35	9.6	192	93	27	16	15	53	25	13
Harvest Date												
Two-Months Earlier	54a†	108a	38a	11.6a	257a	117a	27ab	16a	15b	56a	32a	17a
One-Month Earlier	63a†	85b	40a	8.4b	126b	81b	36a	13b	21a	45b	22b	13b
Scheduled Harvest	53a†	65c	26b	6.1c	160b	48c	26b	10c	10b	36b	21b	9c
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	NS	*	*	*	*	*	*	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.6. The effect of variety, nitrogen rate, and harvest date on micronutrient content of energy cane, plant cane (2013) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**Cu**		**Fe**		**Mn**		**Zn**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	---------------mg kg^{-1} DM---------------							
Variety								
Ho 02-113	3.33	2.36	173	140	15	77	12	17
US 72-114	2.59	2.47	243	133	17	66	18	15
N Rate kg ha^{-1}								
0	2.66	2.22	189	111	17	74	16	15
56	2.87	2.15	140	142	15	67	14	16
112	3.18	2.39	243	151	16	75	17	17
224	3.21	2.89	260	140	16	71	16	18
Harvest Date								
Two-Months Earlier	3.18a	2.53a	434b	150ab	18a	68a†	13b	17a†
One-Month Earlier	2.30b	2.26b	438b	96b	11b	73a†	18a	16a†
Scheduled Harvest	3.47a	2.45ab	537a	162a	19a	74a†	15ab	16a†
Variety	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	*	*	*	*	NS	*	NS
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.7. The effect of variety, nitrogen rate, and harvest date on micronutrient uptake of energy cane, plant cane (2013) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**Cu**		**Fe**		**Mn**		**Zn**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	----------kg ha^{-1} DM----------							
Variety								
Ho 02-113	0.08	0.04	7.13	1.89	0.43	0.98	0.34	0.20
US 72-114	01.0	0.03	4.30	1.68	0.47	0.88	0.54	0.23
N Rate kg ha^{-1}								
0	0.06	0.03	4.26	1.64	0.40	0.10	0.38	0.18
56	0.08	0.03	4.06	1.93	0.42	0.94	0.39	0.22
112	0.09	0.03	8.11	1.62	0.52	0.83	0.55	0.30
224	0.11	0.04	6.43	1.94	0.46	0.94	0.44	0.16
Harvest Date								
Two-Months Earlier	0.09ab	0.04a	1.23b	2.46a	0.51a	1.03a	0.38a†	0.26a
One-Month Earlier	0.07b	0.03b	1.32b	1.23b	0.32b	0.94ab	0.52a†	0.21b
Scheduled Harvest	0.10a	0.03b	1.46a	1.66ab	0.51a	0.81b	0.43a†	0.18b
Variety	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	*	*	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey's post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.8. The effect of variety, nitrogen rate, and harvest date on macronutrient content of energy cane, first ratoon (2014) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	---g kg^{-1} DM---											
Variety												
Ho 02-113	3.1	8.0	1.2	0.8	6.7	84	1.0	3.2	0.5	0.9	0.6	0.8
US 72-114	3.1	8.0	1.4	0.7	6.9	8.0	0.5	3.1	0.4	1.0	0.5	0.9
N Rate kg ha^{-1}												
0	2.9	7.5	1.5	0.8	7.1	8.1	0.7	2.8	0.4	0.8	0.8	0.9
56	2.6	7.6	1.3	0.7	6.9	8.1	0.6	2.9	0.4	0.9	0.6	0.8
112	2.9	8.1	1.2	0.7	6.5	8.1	0.7	3.3	0.4	1.0	0.4	0.8
224	3.9	8.6	1.1	0.7	6.7	8.3	0.9	3.7	0.5	1.2	0.4	0.8
Harvest Date												
Two-Months Earlier	3.2a†	8.9a	1.2c	0.8a	7.0a†	9.5a	0.7a†	2.9b	04a†	1.0a†	0.5b	0.8a†
One-Month Earlier	2.9a†	7.8b	1.3b	0.8a	6.7a†	8.4b	0.7a†	3.2a	04a†	1.0a†	0.6a	0.8a†
Scheduled Harvest	3.2a†	7.2c	1.4a	0.6b	6.8a†	6.5c	0.7a†	3.4a	04a†	1.0a†	0.6a	0.9a†
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	NS	*	*	*	NS	*	NS	*	NS	NS	*	NS
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.9. The effect of variety, nitrogen rate, and harvest date on macronutrient uptake of energy cane, first ratoon (2014) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	----------kg ha^{-1} DM----------											
Variety												
Ho 02-113	64	116	25	11	143	121	20	48	10	14	11	12
US 72-114	58	105	25	10	126	103	9	42	7	14	10	11
N Rate kg ha^{-1}												
0	44	93	25	10	118	98	11	35	6	11	13	11
56	50a	98	25	10	131	103	11	37	7	11	11	10
112	62	119	26	11	140	119	15	51	9	16	10	12
224	86a	133	25	11	149	127	20	57	11	18	8	13
Harvest Date												
Two-Months Earlier	51b	106a†	20b	10a†	117b	113a	12b	34c	7b	12b	8c	9b
One-Month Earlier	60b	106a†	26a	11a†	137ab	115a	15a	45b	8ab	14b	11b	11b
Scheduled Harvest	70a	121a†	29a	11a†	148a	108a	16a	56a	10a	17a	13a	15a
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	NS	*	*	*	NS	*	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey's post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.10. The effect of variety, nitrogen rate, and harvest date on micronutrient content of energy cane, first ratoon (2014) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**Cu**		**Fe**		**Mn**		**Zn**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	---------------mg kg^{-1} DM---------------							
Variety								
Ho 02-113	3.53	2.55	46	108	27	92	12	18
US 72-114	2.77	2.40	36	101	21	89	10	15
N Rate kg ha^{-1}								
0	2.95	2.16	36	104	28	87	14	16
56	2.89	2.14	36	101	26	89	11	15
112	3.13	2.46	54	98	22	90	10	17
224	3.63	3.13	38	115	20	96	10	18
Harvest Date								
Two-Months Earlier	3.51a	2.74a	63a	112b	26a	91a†	11b	15a†
One-Month Earlier	2.99b	2.57ab	30b	136a	24b	89a†	11b	17a†
Scheduled Harvest	2.96b	2.10b	30b	66c	22b	92a†	12a	17a†
Variety	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	*	*	*	*	NS	*	NS
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey's post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.11. The effect of variety, nitrogen rate, and harvest date on micronutrient uptake of energy cane, first ratoon (2014) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**Cu**		**Fe**		**Mn**		**Zn**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	---------------------------kg ha^{-1} DM---------------------------							
Variety								
Ho 02-113	0.06	0.04	0.96	1.45	0.55	1.34	0.21	0.27
US 72-114	0.06	0.03	0.65	1.40	0.38	1.24	0.22	0.20
N Rate kg ha^{-1}								
0	0.05	0.03	0.59	1.23	0.46	1.10	0.23	0.20
56	0.06	0.03	0.67	1.26	0.50	1.15	0.21	0.20
112	0.07	0.04	1.07	1.45	0.47	1.38	0.21	0.25
224	0.08	0.05	0.90	1.76	0.45	1.52	0.21	0.28
Harvest Date								
Two-Months Earlier	0.06a†	0.03a†	1.15a†	1.34a†	0.43b	1.09b	0.17c	0.19c
One-Month Earlier	0.06a†	0.04a†	0.61a†	1.82a†	0.45ab	1.23b	0.22b	0.23b
Scheduled Harvest	0.06a†	0.03a†	0.66a†	1.12a†	0.52a	1.55a	0.25a	0.28a
Variety	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	NS	NS	NS	NS	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.12. The effect of variety, nitrogen rate, and harvest date on macronutrient content of energy cane, second ratoon (2015) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	----------g kg^{-1} DM----------											
Variety												
Ho 02-113	3.2	6.8	1.5	1.4	7.5	9.1	1.1	2.8	0.7	1.1	0.6	0.7
US 72-114	3.2	6.6	1.7	1.3	7.3	8.3	0.7	2.5	0.7	1.2	0.5	0.8
N Rate kg ha^{-1}												
0	2.6	5.9	1.8	1.5	8.0	8.8	0.8	2.2	0.6	0.9	0.9	0.9
56	2.6	6.3	1.6	1.3	7.6	8.8	0.8	2.4	0.6	1.0	0.6	0.7
112	3.2	7.0	1.5	1.3	7.0	8.5	1.0	2.9	0.8	1.3	0.4	0.7
224	4.4	7.7	1.5	1.3	7.2	8.8	1.0	3.1	0.8	1.4	0.4	0.7
Harvest Date												
Two-Months Earlier	3.3a	8.0a	1.7a	1.2b	8.7a	9.2a	0.9ab	2.3b	0.7a	1.2a	0.5ab	0.8a†
One-Month Earlier	3.3a	6.7b	1.6b	1.4a	7.3b	8.7ab	1.0a	2.8a	0.7a	1.1b	0.6a	0.8a†
Scheduled Harvest	3.0b	5.4c	1.4c	1.3b	6.2c	8.2b	0.8b	2.8a	0.6b	1.1b	0.5b	0.8a†
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	*	*	*	*	*	*	*	*	*	*	NS
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey's post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.13. The effect of variety, nitrogen rate, and harvest date on macronutrient uptake of energy cane, second ratoon (2015) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	N		P		K		Ca		Mg		S	
	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf
	-------kg ha^{-1} DM-------											
Variety												
Ho 02-113	65	143	32	29	146	188	22	57	15	24	11	17
US 72-114	63	143	29	27	136	178	14	60	13	27	9	15
N Rate kg ha^{-1}												
0	40	85	27	21	113	128	11	32	8	13	13	14
56	48	122	29	25	137	171	15	48	11	19	10	15
112	71	172	33	32	151	212	23	75	17	33	9	17
224	98	190	33	33	162	221	24	79	19	36	8	18
Harvest Date												
Two-Months Earlier	46b	140ab	23b	21b	116b	158b	12b	39b	10b	21b	7b	13b
One-Month Earlier	73a	158a	34a	32a	155a	199a	21a	69a	16a	28a	12a	18a
Scheduled Harvest	73a	130b	34a	30a	151a	192a	21a	67a	15a	26a	12a	17a
Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	*	*	*	*	*	*	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey's post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.14. The effect of variety, nitrogen rate, and harvest date on micronutrient content of energy cane, second ratoon (2015) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	Cu		Fe		Mn		Zn	
	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf	Stalk	Leaf
	---------------------------mg kg^{-1} DM---------------------------							
Variety								
Ho 02-113	3.32	2.81	74	177	51	105	19	24
US 72-114	4.50	2.77	74	170	33	98	21	17
N Rate kg ha^{-1}								
0	3.47	2.37	56	151	49	104	24	20
56	3.52	2.58	58	155	42	99	19	20
112	4.13	2.90	106	181	39	100	19	20
224	4.52	3.31	76	206	38	103	18	23
Harvest Date								
Two-Months Earlier	4.28a	3.26a†	105a	285a	48a	101ab	22a	18a†
One-Month Earlier	4.16ab	2.70a†	83a	129b	46a	108a	21b	21a†
Scheduled Harvest	3.29b	2.41a†	34b	105b	32b	96b	17c	24a†
Variety	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	NS	*	*	*	*	*	NS
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

Table 2.15. The effect of variety, nitrogen rate, and harvest date on micronutrient uptake of energy cane, second ratoon (2015) at St. Gabriel, LA. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**Cu**		**Fe**		**Mn**		**Zn**	
	Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
	---kg ha^{-1} DM---							
Variety								
Ho 02-113	0.07	0.06	1.46	3.53	0.96	2.22	0.36	0.53
US 72-114	0.09	0.06	1.30	3.60	0.62	2.15	0.40	0.38
N Rate kg ha^{-1}								
0	0.05	0.03	0.78	2.16	0.71	1.54	0.36	0.30
56	0.06	0.05	1.00	2.88	0.76	1.97	0.35	0.43
112	0.09	0.07	2.20	4.30	0.84	2.60	0.41	0.52
224	0.10	0.09	1.54	4.91	0.85	2.62	0.40	0.57
Harvest Date								
Two-Months Earlier	0.06b	0.06a†	1.47ab	5.03a	0.65b	1.71b	0.30b	0.31b
One-Month Earlier	0.10a	0.06a†	1.83a	3.17b	0.96a	2.55a	0.44a	0.50ab
Scheduled Harvest	0.08a	0.06a†	0.84b	2.49b	0.77b	2.28a	0.40a	0.55a
Variety	NS	NS	NS	NS	NS	NS	NS	NS
N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date	*	NS	*	*	*	*	*	*
Variety*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Harvest Date*N Rate	NS	NS	NS	NS	NS	NS	NS	NS
Variety*N Rate*Harvest Date	NS	NS	NS	NS	NS	NS	NS	NS

† Values with same letter within a column for each factor indicate no significant differences based on the Turkey‘s post-hoc analysis
NS Not significant ($P > 0.05$); *, significant at $P < 0.05$.

2.4 Conclusions

This study clearly demonstrated that energy cane yield (stalk and leaves), quality parameters (TRS, brix, sucrose, and fiber), chemical composition (hemicellulose, cellulose, and lignin), and nutrient concentration and uptake were significantly affected by harvest date. There was no apparent impact of variety and N rate (except for the TRS content) on all these parameters. Harvesting energy cane one- and two- months earlier than the scheduled harvest date will potentially lower the stalk and leaf yields, sugar quality parameters, and fiber content. The lignocellulosic component and nutrient concentration and uptake did not show consistent trend in response to harvest date. The maturity of the energy cane really matters in short-growing season in the temperate climate. For future research, the role of ripener in energy cane production should be evaluated.

Another notable outcome from this study was that the application of N did not offer any advantage in terms of yields, sugar quality parameters, lignocellulosic component, and acquisition of plant-essential nutrients from the soil over the unfertilized-N plots for the three successive cropping years. Energy cane appears to be more efficient in the utilization of applied nutrients thus eliminating large application of nutrients particularly N which is considered a big investment in cane production. Therefore, it is more economical, sustainable, and environmental friendly due to reduction of risk arising from excessive application of N. This study showed also the potential use of residue (leaves) as an additional source of feedstock for energy production. However, the value of residues in terms of CO_2 sequestration and nutrient cycling if left on the field versus harvesting for additional feedstock should be weighed out carefully. The long-term effect of continuous farming coupled with complete removal of leaf biomass from the field potentially includes decline in soil quality and productivity.

The outcomes of this study provide insights on the areas of research to focus when considering earlier harvest dates and residue collection (whole plant harvesting) in energy cane production. These include the role of ripeners application on energy cane yield, fiber composition, and nutrient removal rate, and documentation on the long-term impact of whole plant harvesting on soil quality and productivity.

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Chapter 3. Yield, Quality, Biomass Chemical Composition and Nutrient Uptake of Different Cane Varieties Planted as Whole Stalk and Billet

3.1 Introduction

The depletion of our natural resources particularly coal has stimulated active research interest in nonpetroleum, renewable, and nonpolluting fuels. More recently, plant biomass has been considered as a feedstock for biofuel production. These include the first-generation fuels made from edible portions of plants (starch, sucrose, and seed oils) and second-generation biofuels from non-edible cell wall components that comprise the majority of plant biomass (cellulosic biomass) (Laser and Lynd, 2014). The potential cellulosic feedstock sources are corn (*Zea mays*), sugarcane (*Saccharum officinarum*), forest and crop residues, dedicated energy crops like energy cane (*Saccharum spp.*), sweet sorghum (*Sorghum bicolor*), and switchgrass (*Panicum virgatum*). The quality, availability and accessibility of biomass feedstocks are a critical part of the biofuel industry. Understanding the production (logistics of feedstock establishment, harvest, storage, and transport) and consumption or conversions of biomass feedstocks are very important in selecting the most suitable biomass feedstock source in a given area. Biomass quality can drastically lower the net energy output, both limiting the effectiveness of conversion and decreasing the heating value (Jenkins et al., 1998). Also, the ashes and inorganic elements produced during combustion may cause a number of serious problems to power plants through slagging, corrosion, and fouling (Misra et al., 1993). Among the dedicated energy crops, perhaps the most encouraging component of energy cane as a biofuel feedstock is that it has a higher yield potential, in tons of biomass per hectare and minimal inputs than traditional sugarcane varieties, sweet sorghum, switch grass, and other dedicated energy crops (Mark et al., 2009). Also, the planting and harvesting practices for energy cane is very much similar to those presently utilized in sugarcane production. The presence of existing facilities, equipment and expertise in producing a heavy-tonnage perennial crop like sugarcane would give a better prospect of energy cane production a comparative advantage with other potential nontraditional feedstock crops.

In Louisiana, whole stalk planting has been traditionally practiced for sugarcane production. Sugarcane is usually planted in late summer months (August-September) and starts to germinate and produce shoots but ceases its growth during winter months (December-January) due to saturated soils and several freezes. This practice of whole stalk planting was adopted to overcome an often harsh winter climate and stalk rot damage (Hoy et al., 2004). Stalk rots can cause rotting of planted cane stalks and found to be more severe when cane stalks are exposed to environmental stress (Yin and Hoy, 1998). However, the high cost of labor and equipment required in whole stalk planting makes this planting method less popular. Planting is the most expensive operation in cane production system with an estimated cost of $2,000 per hectare depending on region (Roka et al., 2009). The type of planting materials and seeding rate can influence early season cane stand population, number of millable stalk, and overall cane yield (Orgeron et al., 2007). For these reasons, the adoption of the billet planting was of great interest. The benefits of billet planting is having the ability to plant more hectares of sugarcane in a given time period with less labor.

The total area planted per day for whole stalk hand planting, whole stalk machine/one-row billet planters, and three-row billet planters were estimated to be three, five, and sixteen hectares, respectively (Salassi et al., 2014). Total farm production costs for a grower producing energy cane as a biomass feedstock were then estimated to be approximately $2,029 to $2,055 ha^{-1}. Furthermore, with a low seed cane expansion planting ratio and harvest through a fourth stubble crop, total energy cane production costs were estimated to be $113 per dry metric ton of feedstock.

At higher planting ratios of billets planting system, projected total energy cane production costs were below $70 per metric ton. This makes billet planting system more economical than the predominant whole-stalk machine planting system (Salassi et al., 2013). In addition, the adoption of billet planting method in Louisiana was further encouraged by the ease of billet harvesting. The wide planting of LCP 85-384, a high yielding cane variety but often lodges, resulted in the interest with billet harvesting using chopper harvester in Louisiana sugar industry (Milligan et al., 1994). Pyneeandee et al. (2001) reported that significant reductions in labor could be realized if a modified chopper harvester was utilized to prepare billets and then billets were mechanically planted. They also noted that the planting density achieved with the mechanized approach and the germination of the planted setts was comparable to manual methods.

Chanda (2015) found that billet-planted cane produced higher shoot population and stalk count than whole stalk-planted cane under favorable conditions. However, under adverse conditions, both planting materials produced similar shoot population and stalk number. These findings suggest that both planting materials can be used for cane production in tropical areas, however, whole stalk-planted cane is a better choice for temperate climate region because the uncut stalks have more food reserve and less exposed surfaces for pathogen attacks than billets.

While there were reported benefits, there were also several issues associated with billet planting method; producers and industries observed greater crop stand problem, higher seed-cane costs and lower yield with billet planting than with whole stalk planting which prevented the full-scale adoption of billet planting in Louisiana sugarcane production systems (Hoy et al., 2004; Benda et al., 1978; Croft, 1998; Viator et al., 2005; Johnson et al., 2011; Yin and Hoy, 1997; Yin and Hoy, 1998).

Estimating the expected production costs and the suitability of planting and harvesting energy cane as a potential feedstock to support the emerging cellulosic biofuel industry in the southern USA, both from a mechanical and economical perspective are very important. The current state of knowledge on optimal planting method for sugarcane production is considered not well-established. For this reason, research on this particular cultural management practice should be pursued for cane for energy production purposes to optimize productivity and help meet the feedstock demand of the emerging biofuel industry in this region.

The goal of this study was to evaluate the influence of type of planting materials on energy cane yield, quality, and biomass composition. The specific objectives were to assess the growth and yield performance of the different energy cane varieties under whole stalk and billets planting method and to determine the biomass composition and nutrient removal rate of different energy cane varieties planted as whole stalks and billets.

3.2 Materials and Methods

3.2.1 Site location, experimental design and layout

This study was established at the Louisiana State University AgCenter Sugar Research Station (30º15'47"N 91º05'54"W) in St. Gabriel, Louisiana from 2013 to 2015. The soil is Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent). Before planting, composite soil samples (16 cores per quadrant) were randomly collected for initial soil chemical analysis. The samples were dried, ground, and extracted with Mehlich-3 solution (Mehlich, 1984) to determine concentration of several plant-essential nutrients. Carbon:nitrogen (C:N) ratio was determined using CN 91 analyzer (Model: Vario el cube; Manufacturer: Elementar). The soil had an initial pH value of 5.5, C:N ratio (6:1), phosphorus (34 mg kg^{-1}), potassium (170 mg kg^{-1}), magnesium (458 mg kg^{-1}), sulfur (10.8 mg kg^{-1}), and copper (3.5 mg kg^{-1}).

The plot size was 12 m by 1.83 m containing two bedded rows. The treatments included six cane varieties (four energy cane and two sugarcane) and two types of planting scheme (whole stalk and billet). The four energy cane varieties were Ho 02-113, US 72-114, Ho 06-9001, and Ho 06-9002 while the two sugarcane varieties were L 01-299, and L 03-371. Treatments were arranged in a split plot in randomized complete block design where planting method was designated as the main plot and variety as sub-plot and was replicated four times.

3.2.2 Planting, fertilization, harvesting and plant analysis

Planting was done on September 13 to 14, 2012 and two types of planting materials were used in this experiment: whole stalks and billets. Billets were obtained by cutting standing cane stalks with a combine harvester that automatically removed the tops and chopped the stalk with an average length of about 55 cm and have at least three buds per billet. Bedded rows with 1.8 m were opened wherein 5 to 6 running billets were placed. For whole-stalk planting, stalks of different cane varieties were manually cut with cane knives. The average length of whole stalks were 1.81, 1.82, 1.97, 1.92, 2.07, and 2.15 m for the cane varieties Ho 02-113, Ho 06-9001, L 01-299, L 03-371, US 72-114, and Ho 06-9002, respectively. The average number of buds on each whole stalk was 13, 13, 12, 13, 12 and 11 for Ho 02-113, Ho 06-9001, L 01-299, L 03-371, US 72-114, and Ho 06-9002, respectively. Three whole stalks were placed side by side in the furrow with 6-8 cm overlapping for each run. The whole stalks were planted manually to ensure uniform distribution of planting materials. In the middle of April, urea-ammonium nitrate (UAN; 32-0-0) solution with a rate of 120 kg N ha^{-1} was knifed-in near the shoulder of each bed at 15 cm depth.

At harvest, sugarcane stalks were cut from each plot using a Case IH 8800 Series sugarcane harvester (Case IH Agriculture, Racine, WI). Before harvesting the middle row of each plot, ten (sugarcane varieties) or fifteen (energy cane varieties) cane plants were randomly and manually cut using cane knives from the base. The sub-sampled plants were partitioned into stalks and leaves and then weighed separately to get the fresh weight. Stalks were then shredded and analyzed for sugar quality parameters using Spectracane Near Infrared System (Bruker Coporation, Billerica, Massachusetts) to determine theoretical recoverable sugars (TRS), sucrose content, total soluble solids (Brix), and fiber content. Following the sugar quality analysis, the shredded stalk and leaf samples were dried at 60°C for 48 hours, ground to pass a 1-mm sieve, and analyzed for total N using CN 91 analyzer (Model: Vario el cube; Manufacturer: Elementar), elemental composition based on nitric acid-hydrogen peroxide digestion procedure followed by Inductively Coupled Plasma (ICP) - Optical Emission Spectroscopy (OES). For this study, the nutrient uptake was computed as = [nutrient concentration x stalk dry weight]. Lignocellulosic composition was determined using ANKOM^{2000} Filter Bag method. Ground stalk samples weighing 0.5 g was placed in ANKOM F57 filter bags and heat sealed and underwent a series of extractions for Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL). The residue after NDF extraction is predominantly composed of hemicellulose, cellulose and lignin while the ADF extraction is composed of cellulose and lignin and ADL residue represents lignin. The different lignocellulosic composition was computed using difference method:

% Hemicellulose = % NDF – % ADF;

% Cellulose = % ADF – % ADL; and

% Lignin = % ADL

3.2.3 Data Analysis

Statistical analysis was done using SAS 9.4 (SAS Institute, 2012). Variables treated as main effects in the analysis of variance (ANOVA) were planting scheme and cane variety. Appropriate interactions were tested for planting method and cane variety. Millable stalk yield, nutrient concentration and uptake, and fiber composition means were compared by Tukey–Kramer post-hoc test at 5% level of probability.

3.3 Results and Discussions

The type of planting materials had no effect on millable stalks and leaves dry matter yield for the three cropping years – 2013, 2014 and 2015 (Figures 3.1, 3.2, and 3.3). The average millable stalk yield of the different cane varieties were 18 and 19 Mg ha^{-1} (2013, plant cane), 25 and 22 Mg ha^{-1} (2014, first ratoon), 21 and 19 Mg ha^{-1} (2015, second ratoon), for whole stalk- and billet-planted cane, respectively. The results were comparable to the findings of Hoy et al. (2006); they reported that yields of whole stalk and billet plantings were similar throughout the entire crop cycle of sugarcane. On the other hand, there were varietal differences in yield observed for plant cane (2013) and second ratoon (2015) cropping. The cane varieties L 01-299, L 03-371, Ho 02-113, and US 72-114 consistently showed significantly higher dry stalk yield ($P<0.05$); a dry yield difference of 8 Mg ha^{-1} compared with varieties Ho 06-9001 and Ho 06-9002. The latter varieties are considered energy cane including the Ho 02-113, US 72-114 while L 01-299 and L 03-371 are sugarcane varieties. The average stalk yield for L 01-299, L 03-371, Ho 02-113, and US 72-114 were 28, 25, 23, and 19 Mg ha^{-1}, respectively for the three cropping years. Total dry matter yield varies dramatically by genotypes and environmental conditions. The reported yield for sugarcane varies between 80 to 85 ton dry mass per hectare per year (Moore et al., 1998).

The yield levels of Ho 06-9001and Ho 06-9002 in the current study were similar to the findings of Salassi et al. (2014) particularly for plant cane and first ratoon cropping wherein they got an average dry yield of 17 Mg ha^{-1} (Ho 06-9001) and 15 Mg ha^{-1} (Ho 06-9002). Furthermore, they also projected that energy cane yields of biomass on a dry-ton basis were estimated to be 20.3, 19.8, and 19.3 tons per harvested hectare from crop cycles through fourth, fifth, and sixth stubbles. Another study (Marchiori et al., 2006) reported similar yields using variety SP 70-1143 and SP 71-1406 in Brazil.

For the leaves, significant difference in yield was only observed in second ratoon (2014) and variety Ho 02-113 showed the highest yield at 10 Mg ha^{-1}. According to Gravois et al. (2010), energy cane is expected to provide high leaf biomass yields with values up to 17 Mg ha^{-1} dry weight as reported in experimental plots in Louisiana. The results of this study also showed that leaves dry mass of the different cane varieties was significantly different but not the millable stalk dry mass yield. According to Alexander (1985), green tops and trash represent approximately 25% of the total aboveground biomass in sugarcane and millable stalk the remaining 75%.

Furthermore, results from this study revealed that planting scheme did not affect TRS, BRIX, and sucrose. Hoy et al. (2004) also obtained similar results where stalk sucrose content was not affected by planting method, fungicides, or fertilization. Also, Viator et al. (2005) observed that TRS was similar for whole stalk- and billet-planted canes for all the plantings done from August 2000 to October 2001 except for the 4 kg Mg^{-1} increase for the whole stalk method recorded in October 2000 planting.

On the other hand, there were significant differences observed on these sugar quality parameters between cane varieties. Both cane varieties L 01-299 and L 03-371 obtained significantly higher TRS, BRIX, and sucrose content than the energy cane varieties (Table 3.1). The average TRS, BRIX, and sucrose content were 260 kg Mg^{-1}, 18% and 15%, respectively for L 01-299. While, L 03-371 had an average TRS, BRIX, and sucrose content of 223 kg Mg^{-1}, 19% and 16%, respectively. Also, the amount of moisture is higher with sugarcane than energy cane varieties; this might be due to higher amount of sucrose. For most plant species the primary photosynthetic product, which is produced in the leaf (source) and then translocated to other parts of the plant (sink), is sucrose (Botha, 2009). Most studies to date suggest that sink strength, i.e. the ability of the sink to draw sucrose towards it is strongly linked to sucrose breakdown and plays a major role in the ability of the plant to accumulate biomass (Moore et al., 1998). In the young and actively growing sugarcane stalk, carbon partitioning is favored towards the soluble non-sucrose and structural components (Botha et al., 1996; Singels et al., 2005). During this period of growth the radiation use efficiency (RUE) of sugarcane is substantially higher than during the later stages of growth where sucrose accumulates to high levels (Singels et al., 2005). This indicates the potential for enhanced energy cane production where sucrose levels in the storage tissue are kept relatively low in comparison to a sucrose production system (Alexander, 1985; Terajima et al., 2005). Among the four energy cane varieties tested, Ho 02-113 showed a comparable amount of TRS, BRIX, and sucrose with that of sugarcane varieties. Furthermore, Ho 02-113 had high fiber content which is very important for the lignocellulosic-based biofuel industry. Based on the study conducted by Kim and Day (2011), their results revealed that BRIX levels of energy cane were lower, compared with commercial sugarcane but fiber content was twice much higher for energy cane than sugarcane.

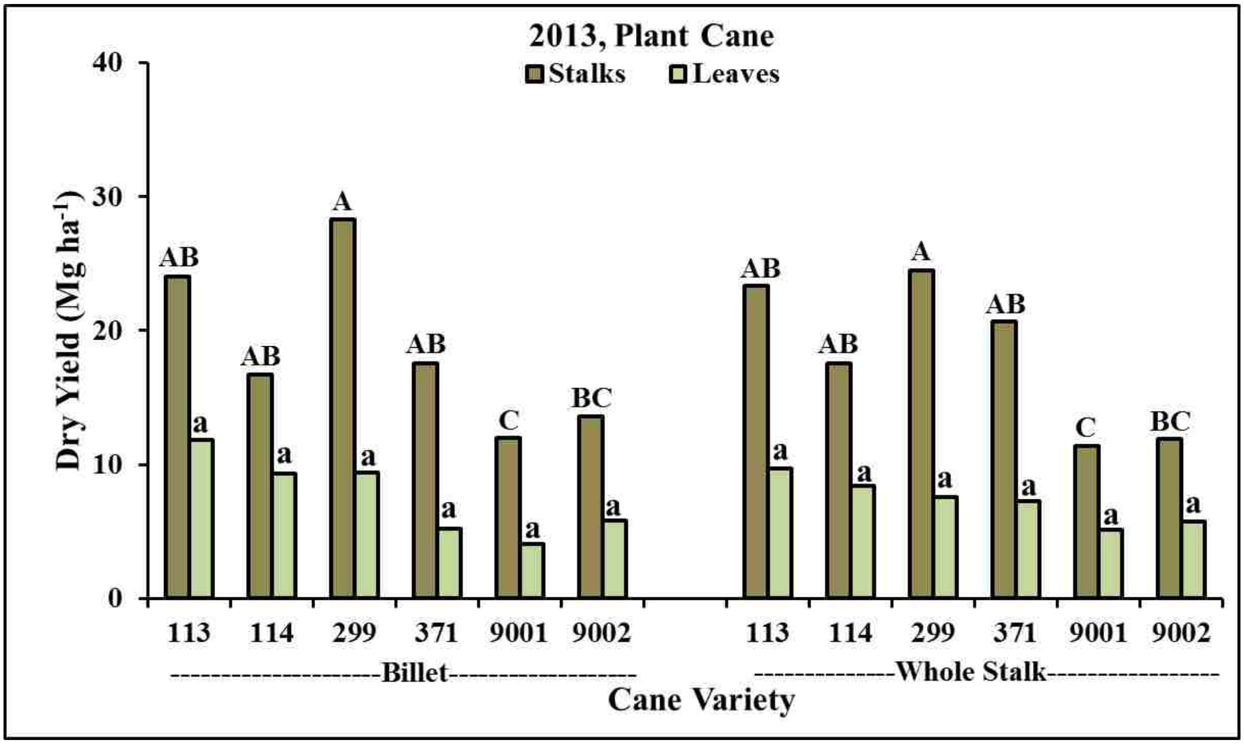

Figure 3.1. Millable stalk and leaves dry mass of different cane varieties planted as whole stalk and billet, plant cane (2013). Bars with the same uppercase (stalks) and lowercase letter (leaves) letter within planting scheme are not significantly different at 0.05 level of confidence.

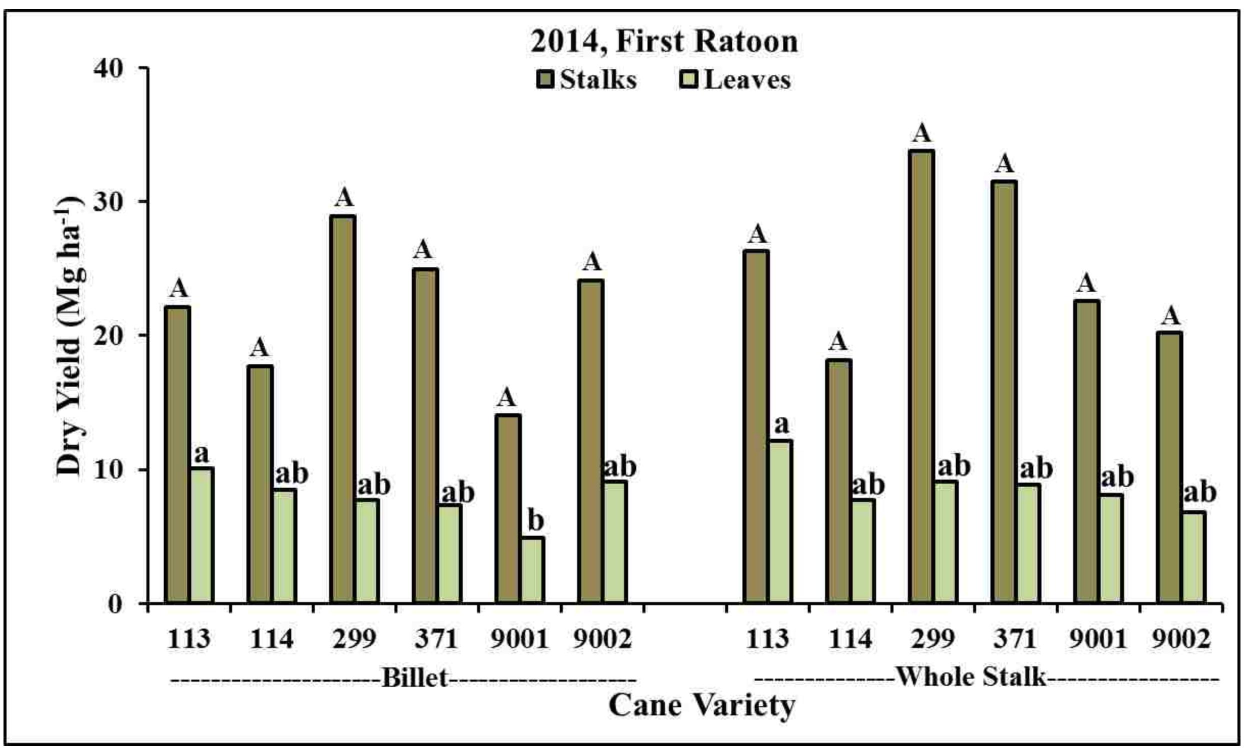

Figure 3.2. Millable stalk and leaves dry mass of different cane varieties planted as whole stalk and billet, first ratoon (2014). Bars with the same uppercase (stalks) and lowercase letter (leaves) letter within planting scheme are not significantly different at 0.05 level of confidence.

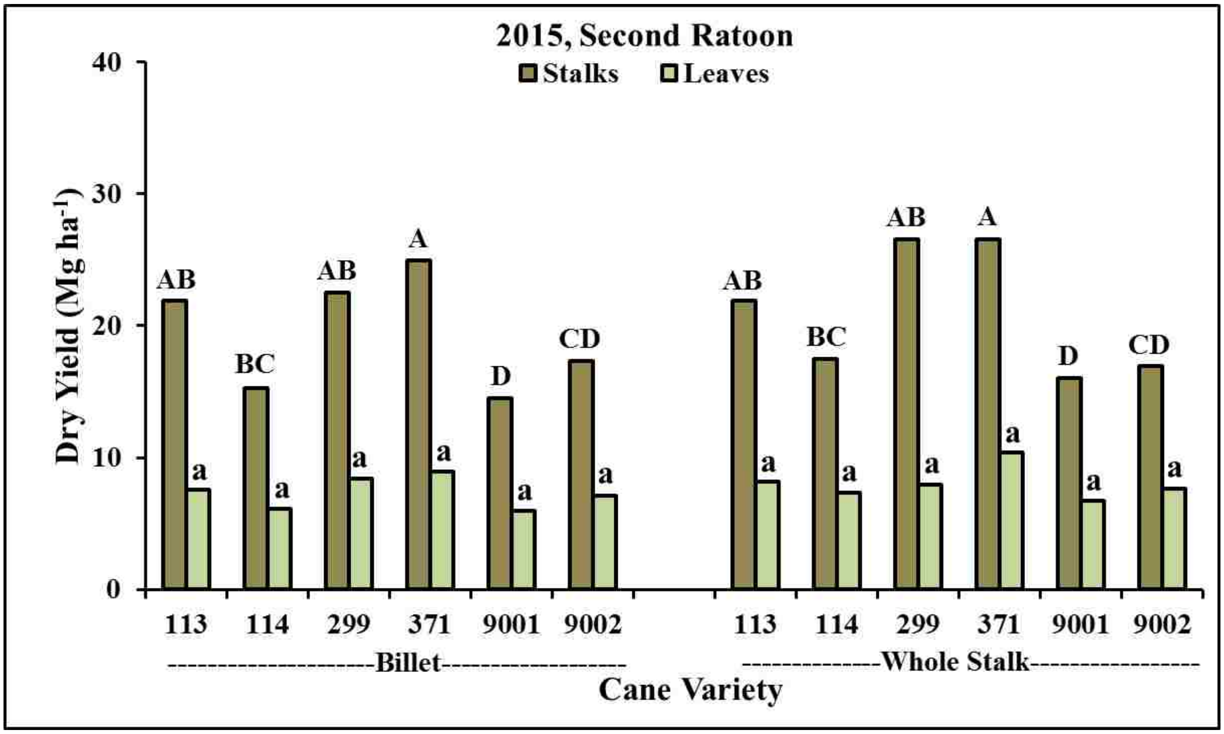

Figure 3.3. Millable stalk and leaves dry mass of different cane varieties planted as whole stalk and billet, second ratoon (2015). Bars with the same uppercase (stalks) and lowercase letter (leaves) letter within planting scheme are not significantly different at 0.05 level of confidence.

Crop biomass composition is essential information for evaluating convertible sugars and fiber availability. One of the challenges of an integrated bio-refinery based on cane-like feedstocks is to make the best use of the high fiber byproduct, called bagasse, after the sugars are extracted. Production of second generation sugars from bagasse using available lignocellulosic pretreatment methods has not been implemented commercially. For this study, the fiber chemical composition showed no significant difference between whole stalk and billet-planted cane. However, hemicellulose, cellulose and lignin content differed between varieties (Figures 3.4, 3.5, and 3.6). Ho 06-9001 and Ho 06-9002 showed significantly higher amount of cellulose in stalk than sugarcane varieties with an average of 31% and 32% across the three cropping years, respectively. On the other hand, sugarcane varieties L 01-299 (28%) and L 03-371 showed significantly higher amount of hemicellulose than energy cane varieties with an average of 38%. Lignin was significantly higher in varieties Ho 02-113 and US 72-114 than the rest of the cane varieties tested. For the leaves, only cane variety US 72-114 had significantly different cellulose content. Across varieties and cropping season, leaves consistently had higher amount of hemicellulose than the stalk. Furthermore, leaves showed significant differences in the amount of cellulose between cane varieties wherein the energy cane varieties Ho 02-113, US 72-114, and Ho 06-9002 showed the highest percentage (~30%). In terms of hemicellulose and lignin content, no significant differences were observed between cane varieties for the three cropping cycle.

Recently, Ogata (2013) evaluated the fiber composition of 207 energy cane genotypes with high fiber content from Instituto Agronômico de Campinas (IAC) breeding program in Brazil. Cellulose composition varied from 26.5% to 54.2% (average of 44.2%), while hemicellulose varied from 16.7% to 26.0% (average of 21.7%) and lignin content ranged from 17.7% to 27.1% (average of 23.5%). These results show that different varieties of energy cane can be selected based on the process of energy production being adopted by sugar mills. For instance, if a sugar mill is looking at producing electricity from burning of biomass, varieties with higher lignin content should be preferred.

In terms of nutrient concentration and uptake, our results showed no significant difference between whole stalk and billet planting scheme. However, significant differences were observed among cane varieties wherein L 01-299 and L 03-371 showed the highest nitrogen concentration (0.22% – 0.40%) and uptake (68 – 81 kg ha^{-1}) in stalk for three cropping years (Tables 4.2, 4.4, and 4.6). Cantarella et al. (2007) reported that sugarcane nitrogen uptake varies from 100 to 300 kg ha^{-1} in order to achieve stalk yields of around 91 Mg ha^{-1}. However, these two sugarcane varieties recorded the lowest concentration and uptake of other macronutrients (P, K, Ca, and Mg) and micronutrients (Cu, Mn, and Zn) particularly for the plant cane in 2013 (Tables 3.8, 3.10, and 3.12). The highest nutrient concentration and uptake for both macro and micro nutrients was obtained by variety Ho 02-113 for stalk and leaf. Furthermore, comparing the stalk and the leaf; the latter obtained higher concentration of N, K, Ca, Mg, Fe, and Zn. But in terms of nutrient uptake, stalk obtained higher amount of N, P, K, Mg, S, Cu, Fe, and Zn than leaf. The N, P, K, Ca, Mg, S of the stalk ranges from 27-138, 11-36, 83-255, 7-39, 7-17, and 5-23 kg ha^{-1}, respectively for 2013, 2014 and 2015. While leaf N, P, K, Ca, Mg, S uptake ranges from 30-91, 3-10, 38-115, 14-44, 6-13, and 3-11 kg ha^{-1}, respectively. Considering the total amount nutrient removed by stalks and leaves, the practice of whole plant harvesting in a long-term may have a subsequent negative impact on soil quality and productivity.

Of the total nutrients in the trash, 75% of the K_2O (81 kg ha^{-1} $year^{-1}$) and 50% of the N (31 kg ha^{-1} $year^{-1}$) are in the tops, indicating the importance of maintaining tops in the soil to sustain soil fertility (Trivelin et al., 2013). A recent study conducted by Leite et al. (2016) showed that the amount of N, P, and K taken up by stalks ranged from 32 to 168, 5 to 57, and 26 to 713 kg ha^{-1}, respectively whereas in dry leaves, the uptake ranged from 19 to 77, 0.6 to 4.9, and 2 to 96 kg ha^{-1}, respectively. Therefore, in high productivity systems, fertilization of N, P, and K is essential to replenish stalk nutrient removal in order to sustainably maintain high yield levels.

The type of planting material has no apparent effects on dry matter yields, quality parameters, and even lignocellulosic composition of energy cane. The lack of differences in nutrient removal rate between whole stalk and billet-planted cane implies that more likely the nutrient requirement and fertilizer recommendation are the same for these two planting method. This study showed that variety (even within energy cane varieties) had greater and consistent impact on all measured variables. There were clear differences in quality components separating cane varieties for sugar from cane varieties for feedstock productions. For the stalk and leaves removal of primary nutrients (N, P, K), there were no outstanding differences observed among varieties. There were noted differences for some nutrients removed by stalk (not leaves) but these are secondary macronutrients (e.g. Mg) and micronutrients (e.g. Mn, Zn) which are typically needed by cane in smaller amounts compared to N, P, K and more often than not, present in the soil in sufficient amount. For all these reasons, there is no apparent need for tailored fertilization guidelines based on energy cane variety. Our results showed the collective nutrient removal by stalk and leaves can be substantial thus for biofuel industry which intends to utilize leaves or residues as additional source of feedstock, it is essential to evaluate the tradeoff between having additional source of feedstock and the nutrients recycled from the residue.

Table 3.1. The effect of planting scheme and variety on quality parameters of cane at St. Gabriel, LA 2013-2015. Results of analysis of variance for each of the factors and their interaction are also presented.

Treatment	**2013, Plant Cane**					**2014, First Ratoon**					**2015, Second Ratoon**				
	TRS kg Mg^{-1}	BRIX	Fiber	Moisture	Sucrose	TRS kg Mg^{-1}	BRIX	Fiber	Moisture	Sucrose	TRS kg Mg^{-1}	BRIX	Fiber	Moisture	Sucrose
		------------%------------					------------%------------					------------%------------			
Planting Scheme															
Billet	188	17.30	19.09	67	13.76	146	16.57	18.58	68.78	11.60	151	15.60	17.57	70	11.55
Whole stalk	175	17.07	19.04	67	13.09	141	16.36	18.81	68.87	11.30	149	15.43	17.80	70	11.40
Variety															
Ho 02-113	155b	16.79a	20.26a	67abc	12.13b	139bc	16.57bc	21.80a	66a	11.31bc	150b	15.40a	19.05b	68bc	11.47b
US 72-114	144b	14.96a	22.78a	66abc	11.06b	87d	13.55d	21.98a	68a	8.02d	106c	13.61c	20.52ab	69b	8.88c
L 01-299	240a	18.70a	13.05b	70ab	16.63a	184ab	18.02ab	12.56b	72a	13.82ab	193a	17.15a	11.88c	73a	13.99a
L 03-371	262a	19.88a	10.46b	71a	18.02a	207a	19.08a	11.13b	72a	15.18a	200a	17.42a	10.20c	74a	14.36a
Ho 06-9001	147b	16.41a	23.43a	64bc	11.64b	102cd	15.03cd	22.30a	66a	9.16cd	125c	14.77b	21.94ab	66bc	10.13c
Ho 06-9002	135b	16.37a	24.39a	63c	11.05b	137bcd	16.54bc	22.41a	66a	11.20bc	123c	14.74b	22.54a	66c	10.03c
Planting Scheme	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Variety	*	NS	*	*	*	*	*	*	NS	*	*	*	*	*	*
Planting Scheme x Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Values within a column (for variety only) with the same letter are not significantly different at P<0.05.
NS Not significant (*P* > 0.05); *, significant at *P* < 0.05.

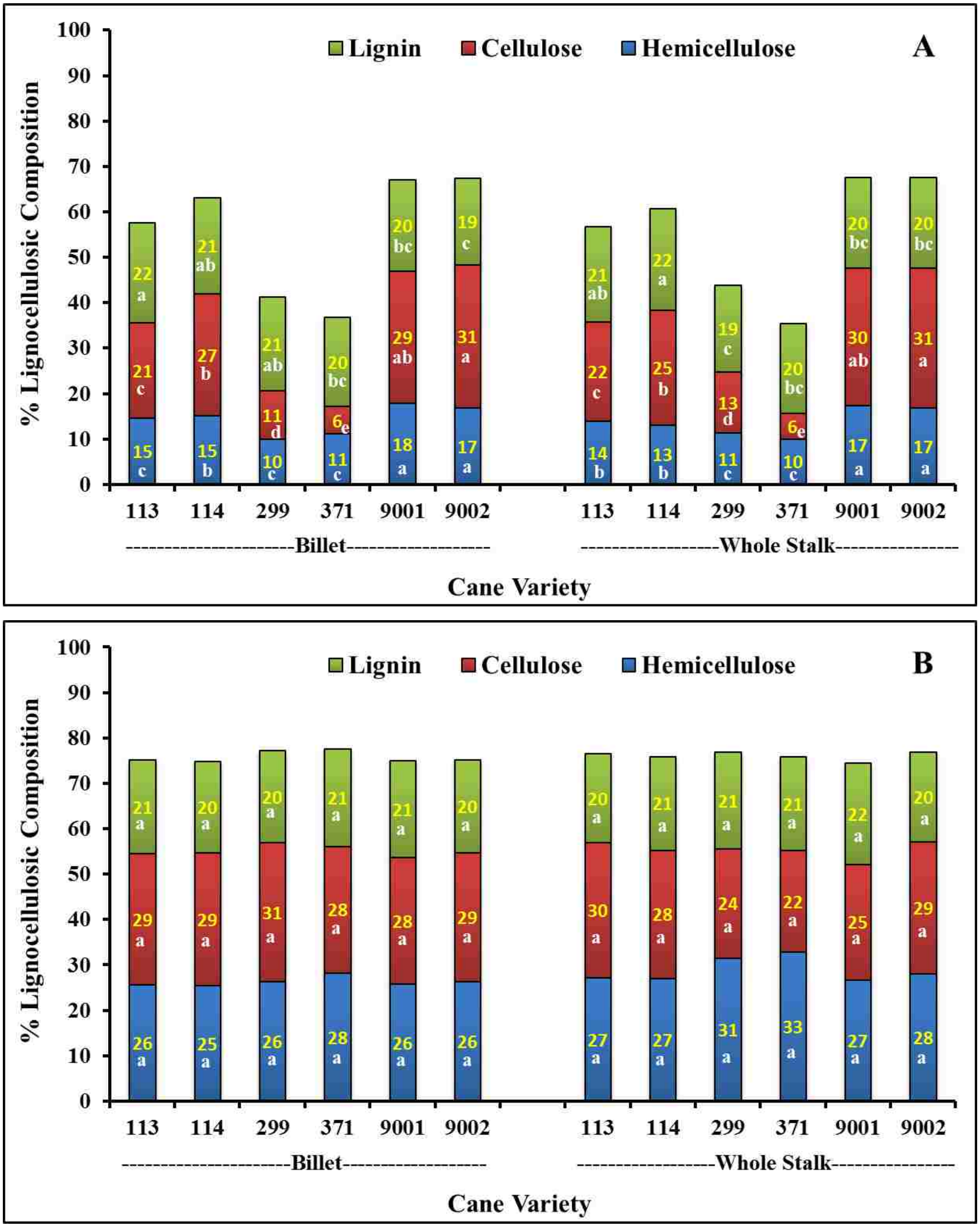

Figure 3.4. Lignocellulosic composition (%) of stalk (A) and leaves (B) of different cane varieties planted as whole stalk and billet, plant cane (2013). For each lignocellulosic component (hemicellulose, cellulose, and lignin), values with same letter within planting scheme are not significantly different at 0.05 level of confidence.

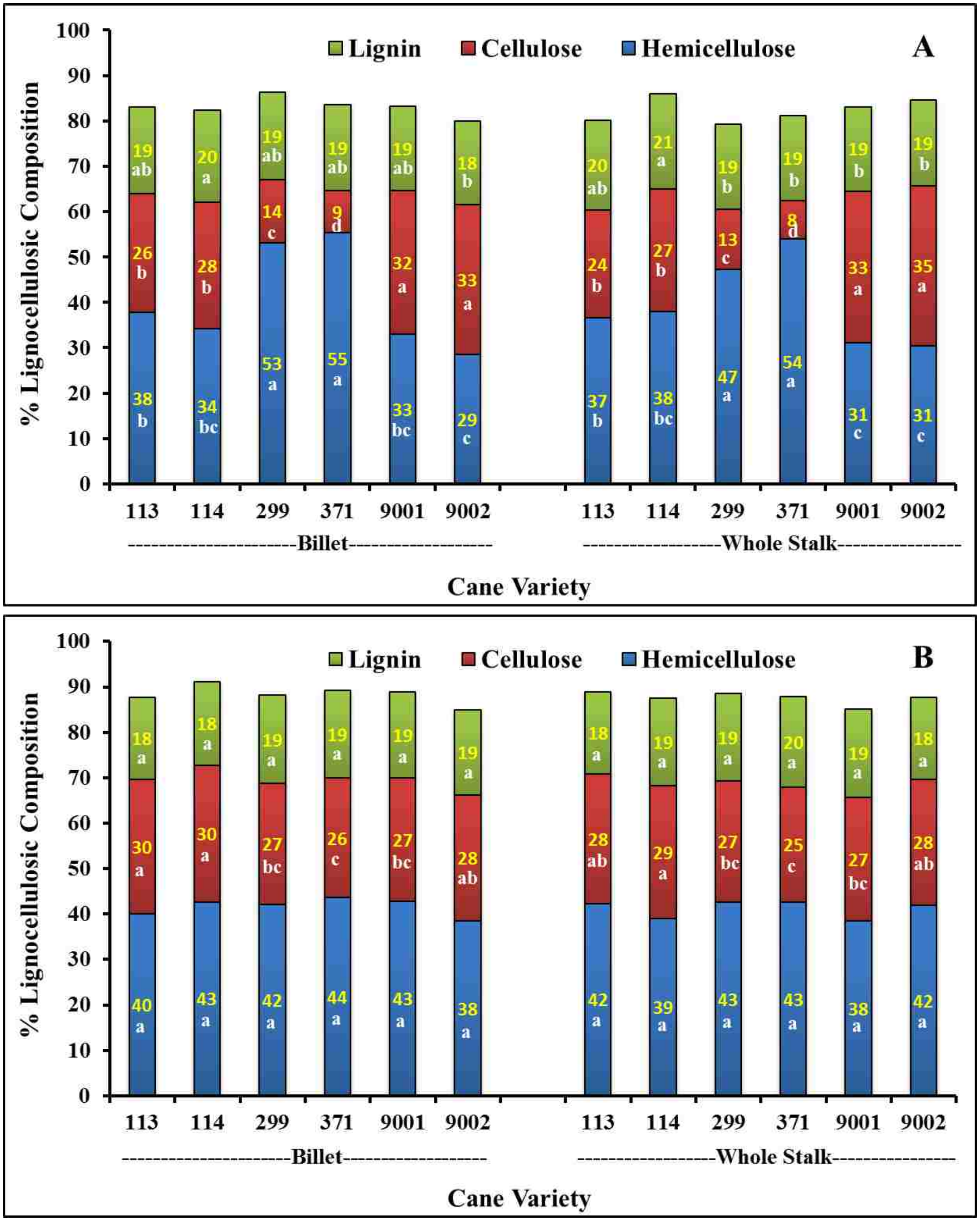

Figure 3.5. Lignocellulosic composition (%) of stalk (A) and leaves (B) of different cane varieties planted as whole stalk and billet, first ratoon (2014). For each lignocellulosic component (hemicellulose, cellulose, and lignin), values with same letter within planting scheme are not significantly different at 0.05 level of confidence.

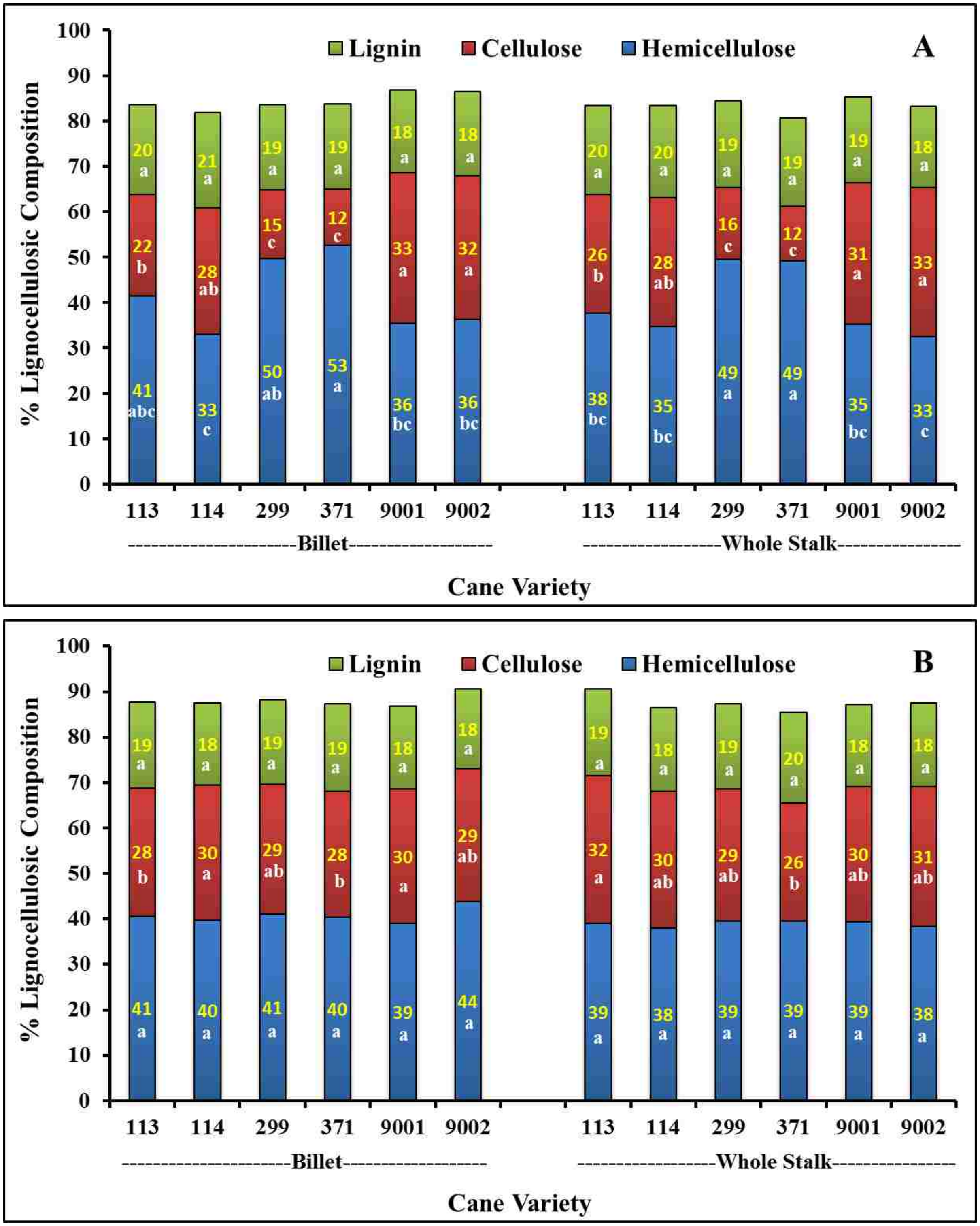

Figure 3.6. Lignocellulosic composition (%) of stalk (A) and leaves (B) of different cane varieties planted as whole stalk and billet, second ratoon (2015). For each lignocellulosic component (hemicellulose, cellulose, and lignin), values with same letter within planting scheme are not significantly different at 0.05 level of confidence.

Table 3.2. Nutrient concentration in cane stalk and leaves planted as whole stalk and billet, plant cane (2013).

Planting Scheme	**Variety**	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		----------g kg^{-1} DM----------											
Billet	113	1.7^{a}	6.8^{a}	1.2^{a}	0.6^{a}	8.4^{a}	6.8^{a}	1.6^{a}	3.7^{ab}	0.7^{ab}	1.0^{a}	1.3^{a}	0.9^{b}
	114	2.3^{a}	7.3^{a}	1.2^{a}	0.7^{a}	8.8^{a}	7.4^{a}	1.1^{b}	3.8^{ab}	0.7^{ab}	1.0^{a}	1.1^{a}	0.9^{ab}
	299	2.5^{a}	6.0^{a}	0.5^{b}	0.5^{a}	4.9^{b}	6.8^{a}	0.8^{bc}	3.4^{bc}	0.6^{b}	1.1^{a}	0.9^{a}	1.0^{ab}
	371	2.3^{a}	7.1^{a}	0.6^{b}	0.6^{a}	4.9^{b}	8.4^{a}	0.6^{c}	2.7^{c}	0.6^{b}	1.1^{a}	0.8^{a}	1.1^{a}
	9001	2.3^{a}	7.3^{a}	1.2^{a}	0.8^{a}	9.3^{a}	8.7^{a}	1.7^{a}	3.8^{ab}	0.8^{a}	1.0^{a}	1.1^{a}	1.1^{ab}
	9002	2.2^{a}	7.5^{a}	1.1^{a}	0.8^{a}	8.2^{a}	8.4^{a}	1.7^{a}	4.0^{a}	0.8^{a}	1.0^{a}	1.1^{a}	1.0^{ab}
Mean		**2.2**	**7.0**	**1.0**	**0.7**	**7.4**	**7.8**	**1.2**	**3.6**	**0.7**	**1.0**	**1.0**	**1.0**
Whole Stalk	113	1.9^{a}	6.4^{a}	1.1^{a}	0.5^{a}	8.5^{a}	6.1^{b}	1.7^{a}	3.8^{ab}	0.7^{bc}	1.1^{a}	1.0^{a}	0.8^{b}
	114	3.1^{a}	6.9^{a}	1.2^{a}	0.7^{a}	8.7^{a}	6.2^{b}	1.0^{b}	3.6^{bc}	0.7^{bc}	1.1^{a}	1.1^{a}	0.9^{ab}
	299	2.7^{a}	7.4^{a}	0.5^{b}	0.6^{a}	4.8^{b}	8.7^{ab}	0.9^{bc}	3.5^{bc}	0.7^{bc}	1.1^{a}	0.9^{a}	1.1^{ab}
	371	2.4^{a}	7.9^{a}	0.6^{b}	0.7^{a}	5.1^{b}	10.7^{a}	0.5^{c}	2.5^{c}	0.6^{c}	1.1^{a}	0.7^{a}	1.2^{a}
	9001	2.4^{a}	7.5^{a}	1.2^{a}	0.8^{a}	8.9^{a}	7.8^{ab}	1.7^{a}	4.3^{a}	0.8^{ab}	1.1^{a}	1.1^{a}	0.9^{ab}
	9002	2.3^{a}	7.3^{a}	1.3^{a}	0.8^{a}	10.2^{a}	8.0^{ab}	1.9^{a}	3.9^{ab}	0.9^{a}	1.0^{a}	1.2^{a}	0.9^{ab}
Mean		**2.5**	**7.2**	**1.0**	**0.7**	**7.7**	**7.9**	**1.3**	**3.6**	**0.7**	**1.1**	**1.0**	**1.0**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.3. Nutrient uptake of cane stalk and leaves planted as whole stalk and billet, plant cane (2013).

Planting Scheme	Variety	N		P		K		Ca		Mg		S	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		------kg ha^{-1} DM------											
Billet	113	40^{b}	82^{a}	28^{a}	7.1^{a}	201^{a}	80^{a}	39^{a}	44^{a}	16^{ab}	11.6^{a}	33^{a}	10.6^{a}
	114	37^{b}	68^{a}	21^{b}	6.3^{a}	147^{b}	70^{ab}	18^{b}	35^{ab}	11^{bc}	9.1^{a}	18^{b}	8.8^{a}
	299	71^{a}	58^{a}	15^{c}	4.8^{a}	138^{bc}	62^{ab}	23^{b}	33^{ab}	17^{a}	10.6^{a}	24^{ab}	9.5^{a}
	371	39^{b}	37^{a}	11^{c}	3.0^{a}	86^{d}	45^{ab}	10^{c}	14^{b}	10^{c}	5.5^{a}	14^{b}	6.1^{a}
	9001	27^{d}	31^{a}	15^{c}	3.5^{a}	112^{c}	38^{b}	20^{b}	16^{b}	9^{c}	4.1^{a}	14^{b}	4.8^{a}
	9002	30^{cd}	44^{a}	15^{c}	4.7^{a}	111^{c}	48^{ab}	24^{b}	23^{ab}	11^{c}	5.9^{a}	15^{b}	5.8^{a}
Mean		***41***	***53***	***18***	***4.9***	***132***	***57***	***22***	***28***	***12***	***7.8***	***20***	***7.6***
Whole Stalk	113	45^{bc}	62^{a}	25^{a}	5.0^{a}	199^{a}	59^{ab}	38^{a}	37^{a}	16^{ab}	10.2^{a}	24^{a}	7.4^{a}
	114	52^{b}	56^{a}	21^{b}	5.3^{a}	147^{b}	50^{ab}	18^{b}	30^{ab}	13^{bc}	9.4^{a}	19^{b}	7.4^{a}
	299	66^{a}	56^{a}	13^{c}	4.7^{a}	116^{bc}	66^{ab}	22^{b}	26^{ab}	17^{a}	8.3^{a}	21^{ab}	8.5^{a}
	371	49^{b}	57^{a}	13^{c}	4.7^{a}	104^{c}	78^{a}	10^{c}	18^{b}	11^{c}	8.3^{a}	15^{b}	8.5^{a}
	9001	28^{d}	38^{a}	14^{c}	3.8^{a}	100^{c}	40^{c}	19^{b}	22^{ab}	9^{c}	5.6^{a}	13^{b}	4.7^{a}
	9002	27^{cd}	44^{a}	15^{c}	4.6^{a}	122^{bc}	47^{bc}	22^{b}	23^{ab}	10^{c}	5.9^{a}	14^{b}	5.3^{a}
Mean		***45***	***52***	***17***	***4.7***	***131***	***57***	***22***	***26***	***13***	***7.9***	***18***	***7.0***

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.4. Nutrient concentration of cane stalk and leaves planted as whole stalk and billet, first ratoon (2014).

Planting Scheme	Variety	N		P		K		Ca		Mg		S	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		----------g kg^{-1} DM----------											
Billet	113	3.4^{a}	6.6^{c}	1.2^{ab}	0.6^{b}	6.8^{b}	6.4^{c}	0.9^{a}	2.9^{bc}	0.4^{a}	0.9^{c}	0.5^{a}	0.7^{c}
	114	3.2^{a}	6.9^{bc}	1.1^{ab}	0.6^{b}	6.9^{ab}	6.1^{c}	0.5^{a}	3.0^{bc}	0.3^{a}	0.9^{c}	0.5^{a}	0.6^{c}
	299	3.2^{a}	8.4^{ab}	0.9^{b}	0.9^{a}	4.3^{c}	10.4^{a}	0.6^{a}	3.9^{a}	0.5^{a}	1.2^{a}	0.5^{a}	1.1^{a}
	371	3.4^{a}	7.2^{bc}	1.0^{b}	0.8^{ab}	4.1^{c}	9.7^{ab}	0.4^{a}	2.6^{c}	0.4^{a}	1.1^{ab}	0.5^{a}	1.1^{ab}
	9001	3.0^{a}	9.2^{a}	1.5^{a}	1.0^{a}	10.3^{a}	9.7^{ab}	1.0^{a}	3.6^{ab}	0.5^{a}	1.0^{bc}	0.8^{a}	0.9^{bc}
	9002	3.4^{a}	8.8^{ab}	1.3^{ab}	0.9^{a}	9.0^{ab}	9.5^{b}	0.9^{a}	3.2^{ab}	0.5^{a}	1.0^{bc}	0.7^{a}	0.9^{c}
Mean		**3.3**	**7.9**	**1.1**	**0.8**	**6.6**	**8.6**	**0.7**	**3.2**	**0.4**	**1.0**	**0.7**	**0.9**
Whole Stalk	113	3.0^{a}	7.4^{c}	1.1^{ab}	0.7^{b}	7.0^{b}	7.5^{c}	0.9^{a}	2.7^{bc}	0.4^{a}	0.8^{c}	0.7^{a}	0.8^{c}
	114	3.5^{a}	7.7^{bc}	1.4^{ab}	0.6^{b}	7.9^{ab}	7.1^{c}	0.4^{a}	3.0^{bc}	0.4^{a}	1.0^{bc}	0.6^{a}	0.9^{c}
	299	4.0^{a}	8.7^{b}	0.8^{b}	0.8^{ab}	3.5^{c}	10.1^{ab}	0.5^{a}	3.8^{a}	0.5^{a}	1.2^{a}	0.4^{a}	1.1^{ab}
	371	3.1^{a}	7.7^{bc}	0.8^{b}	0.8^{ab}	5.0^{c}	10.6^{a}	1.1^{a}	2.7^{c}	0.5^{a}	1.1^{ab}	0.5^{a}	1.2^{a}
	9001	4.5^{a}	8.8^{b}	1.6^{a}	1.0^{a}	10.4^{a}	9.4^{b}	0.9^{a}	3.3^{ab}	0.5^{a}	1.0^{abc}	0.5^{a}	0.9^{c}
	9002	3.3^{a}	9.7^{a}	1.5^{ab}	1.0^{a}	9.8^{ab}	10.0^{ab}	0.9^{a}	3.8^{ab}	0.5^{a}	1.0^{bc}	0.7^{a}	1.0^{bc}
Mean		**3.5**	**8.4**	**1.1**	**0.8**	**6.7**	**9.1**	**0.08**	**3.2**	**0.5**	**1.0**	**0.6**	**1.0**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.5. Nutrient uptake of cane stalk and leaves planted as whole stalk and billet, first ratoon (2014).

Planting Scheme	**Variety**	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		---kg ha^{-1} DM---											
Billet	113	78^{ab}	66^{a}	26^{a}	6^{a}	150^{ab}	62^{a}	19^{a}	29^{a}	10^{a}	8^{a}	11^{a}	6^{a}
	114	58^{b}	56^{a}	19^{a}	5^{a}	118^{ab}	48^{a}	9^{a}	25^{a}	6^{a}	8^{a}	8^{a}	5^{a}
	299	93^{a}	64^{a}	25^{a}	7^{a}	127^{b}	80^{a}	17^{a}	30^{a}	14^{a}	9^{a}	16^{a}	9^{a}
	371	84^{ab}	53^{a}	24^{a}	5^{a}	103^{b}	70^{a}	9^{a}	20^{a}	10^{a}	8^{a}	13^{a}	8^{a}
	9001	40^{b}	45^{a}	22^{a}	5^{a}	144^{ab}	47^{a}	13^{a}	17^{a}	7^{a}	5^{a}	11^{a}	5^{a}
	9002	85^{ab}	80^{a}	33^{a}	8^{a}	225^{a}	86^{a}	21^{a}	29^{a}	12^{a}	9^{a}	17^{a}	8^{a}
Mean		**76**	**62**	**25**	**6**	**143**	**66**	**15**	**25**	**10**	**8**	**13**	**7**
Whole Stalk	113	78^{b}	91^{a}	30^{a}	9^{a}	182^{ab}	87^{a}	24^{a}	33^{a}	12^{a}	10^{a}	18^{a}	10^{a}
	114	64^{b}	61^{a}	24^{a}	5^{a}	143^{b}	55^{a}	7^{a}	23^{a}	7^{a}	8^{a}	10^{a}	7^{a}
	299	138^{a}	79^{a}	25^{a}	7^{a}	118^{b}	90^{a}	19^{a}	35^{a}	17^{a}	11^{a}	15^{a}	10^{a}
	371	96^{b}	69^{a}	27^{a}	7^{a}	151^{b}	93^{a}	31^{a}	24^{a}	16^{a}	10^{a}	16^{a}	11^{a}
	9001	102^{b}	72^{a}	36^{a}	8^{a}	234^{a}	77^{a}	21^{a}	27^{a}	11^{a}	8^{a}	12^{a}	7^{a}
	9002	64^{b}	66^{a}	31^{a}	7^{a}	209^{ab}	70^{a}	19^{a}	25^{a}	10^{a}	7^{a}	14^{a}	7^{a}
Mean		**94**	**74**	**28**	**7**	**164**	**81**	**21**	**29**	**13**	**9**	**15**	**9**

Note: Values within a column within planting with the same letter are not significantly different at $P<0.05$.

Table 3.6. Nutrient concentration of cane stalk and leaves planted as whole stalk and billet, second ratoon (2015).

Planting Scheme	**Variety**	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		----------------g kg^{-1} DM----------------											
Billet	113	2.4^{a}	5.1^{a}	1.1^{a}	0.9^{a}	5.6^{bc}	8.6^{c}	0.9^{a}	2.7^{a}	0.4^{a}	1.0^{c}	0.5^{a}	0.7^{a}
	114	2.3^{a}	5.7^{a}	1.3^{a}	0.9^{a}	6.8^{ab}	8.5^{c}	0.5^{a}	2.4^{a}	0.3^{a}	1.0^{c}	0.5^{a}	0.6^{a}
	299	2.2^{a}	5.4^{a}	1.0^{a}	1.2^{a}	4.6^{c}	10.9^{a}	0.6^{a}	3.4^{a}	0.5^{a}	1.5^{a}	0.5^{a}	0.9^{a}
	371	2.6^{a}	5.1^{a}	1.2^{a}	0.9^{a}	5.2^{bc}	10.7^{ab}	0.4^{a}	2.2^{a}	0.4^{a}	1.3^{b}	0.5^{a}	1.0^{a}
	9001	2.3^{a}	5.1^{a}	1.5^{a}	1.1^{a}	8.0^{a}	10.3^{bc}	1.0^{a}	2.5^{a}	0.5^{a}	1.0^{c}	0.8^{a}	0.8^{a}
	9002	2.6^{a}	5.5^{a}	1.4^{a}	1.0^{a}	7.8^{ab}	9.9^{bc}	0.9^{a}	3.0^{a}	0.5^{a}	1.0^{c}	0.7^{a}	0.7^{a}
Mean		**2.4**	**5.3**	**1.2**	**1.0**	**6.1**	**9.8**	**0.7**	**2.7**	**0.4**	**1.1**	**0.7**	**0.8**
Whole Stalk	113	2.4^{a}	5.0^{a}	1.1^{a}	0.7^{a}	6.8^{bc}	8.3^{c}	0.9^{a}	2.2^{a}	0.4^{a}	0.8^{c}	0.7^{a}	0.6^{a}
	114	2.5^{a}	5.2^{a}	1.2^{a}	0.7^{a}	6.4^{bc}	7.6^{c}	0.4^{a}	2.6^{a}	0.4^{a}	1.1^{bc}	0.6^{a}	0.6^{a}
	299	2.3^{a}	5.1^{a}	1.0^{a}	1.0^{a}	5.0^{c}	10.8^{ab}	0.5^{a}	3.5^{a}	0.5^{a}	1.5^{a}	0.4^{a}	0.9^{a}
	371	2.7^{a}	5.4^{a}	1.2^{a}	1.0^{a}	5.1^{c}	11.1^{a}	1.1^{a}	2.2^{a}	0.5^{a}	1.3^{b}	0.5^{a}	1.1^{a}
	9001	2.7^{a}	4.9^{a}	1.4^{a}	0.8^{a}	8.3^{a}	8.8^{bc}	0.9^{a}	2.2^{a}	0.5^{a}	0.8^{c}	0.5^{a}	0.5^{a}
	9002	2.3^{a}	4.6^{a}	1.3^{a}	0.8^{a}	7.8^{ab}	8.5^{bc}	0.9^{a}	2.6^{a}	0.5^{a}	0.9^{c}	0.7^{a}	0.5^{a}
Mean		**2.5**	**5.1**	**1.2**	**0.8**	**6.3**	**9.6**	**0.8**	**2.6**	**0.5**	**1.1**	**0.6**	**0.7**

Note: Values within a column within planting scheme with the same letter are not significantly differ.ent at $P<0.05$.

Table 3.7. Nutrient uptake of cane stalk and leaves planted as whole stalk and billet, second ratoon (2015).

Planting Scheme	**Variety**	**N**		**P**		**K**		**Ca**		**Mg**		**S**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		-------------------------kg ha^{-1} DM-------------------------											
Billet	113	53^{ab}	39^{ab}	24^{a}	7^{bc}	121^{a}	65^{a}	17^{a}	20^{a}	11^{ab}	8^{b}	7^{a}	5^{c}
	114	36^{b}	35^{b}	20^{a}	5^{c}	103^{a}	52^{a}	11^{a}	15^{a}	8^{b}	6^{b}	5^{a}	4^{c}
	299	51^{ab}	43^{ab}	23^{a}	10^{a}	103^{a}	91^{a}	15^{a}	29^{a}	12^{a}	12^{a}	7^{a}	7^{b}
	371	66^{a}	46^{a}	29^{a}	8^{ab}	127^{a}	94^{a}	12^{a}	20^{a}	12^{a}	12^{a}	9^{a}	9^{a}
	9001	35^{b}	30^{b}	23^{a}	6^{bc}	117^{a}	61^{a}	12^{a}	15^{a}	8^{b}	6^{b}	7^{a}	5^{c}
	9002	45^{ab}	39^{ab}	25^{a}	7^{bc}	133^{a}	70^{a}	16^{a}	22^{a}	10^{ab}	7^{b}	7^{a}	5^{c}
Mean		**49**	**40**	**24**	**7**	**117**	**74**	**14**	**20**	**11**	**9**	**7**	**6**
Whole Stalk	113	54^{ab}	41^{ab}	26^{a}	6^{bc}	151^{a}	67^{a}	21^{a}	18^{a}	12^{a}	7^{b}	8^{a}	5^{c}
	114	42^{ab}	38^{b}	22^{a}	5^{c}	112^{a}	55^{a}	10^{a}	19^{a}	9^{ab}	8^{b}	6^{a}	4^{c}
	299	64^{ab}	41^{ab}	26^{a}	8^{ab}	130^{a}	85^{a}	16^{a}	28^{a}	15^{a}	12^{a}	10^{a}	7^{b}
	371	75^{a}	55^{a}	31^{a}	10^{a}	137^{a}	115^{a}	12^{a}	23^{a}	12^{ab}	13^{a}	10^{a}	11^{a}
	9001	43^{a}	33^{b}	24^{a}	5^{c}	134^{a}	59^{a}	12^{a}	15^{a}	8^{b}	6^{b}	7^{a}	3^{c}
	9002	39^{a}	34^{b}	22^{a}	6^{bc}	128^{a}	64^{a}	16^{a}	20^{a}	10^{ab}	7^{b}	8^{a}	4^{c}
Mean		**55**	**41**	**25**	**7**	**132**	**78**	**15**	**22**	**11**	**9**	**8**	**6**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.8. Nutrient concentration of cane stalk and leaves planted as whole stalk and billet, plant cane (2013).

Planting Scheme	Variety	Cu		Fe		Mn		Zn	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		------------------------mg kg^{-1} DM------------------------							
Billet	113	3.0^{ab}	2.0^{b}	35^{a}	52^{a}	18^{a}	50^{a}	12^{bc}	17^{a}
	114	4.0^{a}	2.0^{b}	39^{a}	51^{a}	13^{ab}	61^{a}	13^{ab}	13^{a}
	299	2.0^{b}	2.0^{b}	32^{a}	67^{a}	9^{b}	46^{a}	8^{c}	13^{a}
	371	2.0^{b}	2.0^{b}	37^{a}	53^{a}	14^{ab}	42^{a}	8^{c}	12^{a}
	9001	3.0^{ab}	3.0^{a}	33^{a}	47^{a}	15^{a}	79^{a}	14^{a}	15^{a}
	9002	4.0^{a}	3.0^{a}	3.9^{a}	55^{a}	15^{a}	71^{a}	13^{ab}	14^{a}
Mean		**3.0**	**2.0**	**36**	**54**	**14**	**58**	**11**	**14**
Whole Stalk	113	3.0^{b}	2.0^{b}	40^{a}	71^{a}	12^{ab}	48^{a}	10^{b}	15^{a}
	114	5.0^{a}	2.0^{b}	45^{a}	75^{a}	13^{ab}	63^{a}	14^{a}	15^{a}
	299	2.0^{c}	2.0^{b}	33^{a}	46^{a}	10^{b}	46^{a}	10^{b}	14^{a}
	371	3.0^{b}	2.0^{b}	48^{a}	96^{a}	14^{ab}	44^{a}	8^{c}	16^{a}
	9001	4.0^{ab}	3.0^{a}	46^{a}	53^{a}	16^{a}	74^{a}	14^{a}	14^{a}
	9002	4.0^{ab}	3.0^{a}	39^{a}	56^{a}	19^{a}	71^{a}	14^{a}	13^{a}
Mean		**3.0**	**2.0**	**42**	**66**	**14**	**58**	**12**	**14**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.9. Nutrient uptake of cane stalk and leaves planted as whole stalk and billet, plant cane (2013).

Planting Scheme	**Variety**	**Cu**		**Fe**		**Mn**		**Zn**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		----------kg ha^{-1} DM----------							
Billet	113	0.08^{a}	0.03^{a}	0.84^{a}	0.60^{a}	0.42^{a}	0.57^{a}	0.28^{a}	0.19^{a}
	114	0.06^{ab}	0.02^{a}	0.66^{ab}	0.47^{ab}	0.23^{b}	0.57^{a}	0.22^{a}	0.12^{b}
	299	0.06^{ab}	0.02^{a}	0.91^{a}	0.63^{a}	0.25^{b}	0.45^{ab}	0.24^{a}	0.12^{b}
	371	0.04^{c}	0.01^{a}	0.65^{ab}	0.27^{b}	0.25^{b}	0.22^{b}	0.15^{b}	0.07^{c}
	9001	0.04^{c}	0.01^{a}	0.40^{b}	0.20^{b}	0.18^{b}	0.33^{ab}	0.17^{b}	0.06^{c}
	9002	0.05^{bc}	0.02^{a}	0.56^{ab}	0.30^{b}	0.20^{b}	0.40^{ab}	0.17^{b}	0.08^{c}
Mean		**0.06**	**0.02**	**0.67**	**0.41**	**0.25**	**0.42**	**0.21**	**0.11**
Whole Stalk	113	0.08^{a}	0.02^{a}	0.93^{a}	0.69^{a}	0.28^{a}	0.47^{ab}	0.23^{a}	0.14^{a}
	114	0.08^{a}	0.02^{a}	0.78^{bc}	0.55^{ab}	0.23^{ab}	0.52^{a}	0.25^{a}	0.12^{b}
	299	0.06^{ab}	0.02^{a}	0.82^{ab}	0.35^{b}	0.24^{ab}	0.35^{b}	0.25^{a}	0.11^{b}
	371	0.05^{bc}	0.02^{a}	0.95^{a}	0.57^{ab}	0.29^{a}	0.33^{b}	0.15^{b}	0.12^{b}
	9001	0.05^{bc}	0.01^{a}	0.49^{c}	0.26^{b}	0.18^{b}	0.38^{b}	0.15^{b}	0.07^{c}
	9002	0.04^{c}	0.02^{a}	0.46^{c}	0.31^{b}	0.23^{ab}	0.40^{ab}	0.17^{b}	0.08^{c}
Mean		**0.06**	**0.02**	**0.74**	**0.45**	**0.24**	**0.41**	**0.20**	**0.11**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.10. Nutrient concentration of cane stalk and leaves planted as whole stalk and billet, first ratoon (2014).

Planting Scheme	**Variety**	**Cu**		**Fe**		**Mn**		**Zn**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		----------------------mg kg^{-1} DM----------------------							
Billet	113	2.0^{a}	2.0^{a}	30^{a}	57^{ab}	30^{a}	88^{bc}	10^{a}	15^{a}
	114	2.0^{a}	2.0^{a}	30^{a}	56^{ab}	20^{a}	95^{a}	10^{a}	10^{a}
	299	2.0^{a}	2.0^{a}	30^{a}	52^{b}	11^{a}	68^{c}	10^{a}	15^{a}
	371	2.0^{a}	2.0^{a}	30^{a}	59^{ab}	18^{a}	72^{c}	9^{a}	15^{a}
	9001	3.0^{a}	3.0^{a}	40^{a}	61^{ab}	23^{a}	95^{a}	13^{a}	14^{a}
	9002	3.0^{a}	3.0^{a}	40^{a}	67^{a}	23^{a}	93^{ab}	11^{a}	12^{a}
Mean		**2.0**	**2.0**	**30**	**58**	**21**	**84**	**10**	**14**
Whole Stalk	113	2.0^{a}	2.0^{a}	30^{a}	50^{ab}	28^{a}	71^{c}	10^{a}	17^{a}
	114	3.0^{a}	2.0^{a}	30^{a}	63^{ab}	23^{a}	110^{ab}	13^{a}	14^{a}
	299	2.0^{a}	2.0^{a}	30^{a}	63^{ab}	12^{a}	73^{bc}	10^{a}	16^{a}
	371	2.0^{a}	2.0^{a}	40^{a}	49^{b}	36^{a}	73^{bc}	11^{a}	16^{a}
	9001	3.0^{a}	3.0^{a}	30^{a}	67^{ab}	24^{a}	120^{a}	12^{a}	15^{a}
	9002	3.0^{a}	3.0^{a}	30^{a}	68^{a}	24^{a}	88^{b}	12^{a}	14^{a}
Mean		**2.0**	**2.0**	**30**	**59**	**24**	**84**	**11**	**16**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.11. Nutrient uptake of cane stalk and leaves planted as whole stalk and billet, first ratoon (2014).

Planting Scheme	Variety	Cu		Fe		Mn		Zn	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		---kg ha^{-1}DM---							
Billet	113	0.05[a]	0.01[a]	0.59[a]	0.57[a]	0.66[a]	0.95[a]	0.22[a]	0.14[a]
	114	0.04[a]	0.02[a]	0.45[a]	0.48[ab]	0.35[a]	0.81[ab]	0.18[a]	0.08[a]
	299	0.05[a]	0.02[a]	0.70[a]	0.40[ab]	0.32[a]	0.53[b]	0.28[a]	0.12[a]
	371	0.05[a]	0.02[a]	0.75[a]	0.44[ab]	0.44[a]	0.53[b]	0.23[a]	0.11[a]
	9001	0.04[a]	0.01[a]	0.60[a]	0.30[b]	0.31[a]	0.46[b]	0.18[a]	0.07[a]
	9002	0.06[a]	0.02[a]	0.85[a]	0.60a	0.54[a]	0.84[ab]	0.27[a]	0.11[a]
Mean		**0.05**	**0.02**	**0.66**	**0.48**	**0.45**	**0.70**	**0.23**	**0.11**
Whole Stalk	113	0.06[a]	0.02[a]	0.94[a]	0.61[a]	0.74[a]	0.91[a]	0.27[a]	0.21[a]
	114	0.06[a]	0.02[a]	0.57[a]	0.48[ab]	0.42[a]	0.85[ab]	0.23[a]	0.11[a]
	299	0.06[a]	0.02[a]	0.94[a]	0.57[ab]	0.40[a]	0.66[b]	0.32[a]	0.15[a]
	371	0.06[a]	0.02[a]	1.26[a]	0.44[b]	1.01[a]	0.66[b]	0.32[a]	0.14[a]
	9001	0.06[a]	0.02[a]	0.66[a]	0.54[ab]	0.53[a]	0.98[a]	0.28[a]	0.12[a]
	9002	0.06[a]	0.02[a]	0.52[a]	0.47[ab]	0.50[a]	0.60[b]	0.25[a]	0.09[a]
Mean		**0.06**	**0.02**	**0.86**	**0.52**	**0.61**	**0.76**	**0.28**	**0.14**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.12. Nutrient concentration of cane stalk and leaves planted as whole stalk and billet, second ratoon (2015).

Planting Scheme	**Variety**	**Cu**		**Fe**		**Mn**		**Zn**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		---------------mg kg^{-1} DM---------------							
Billet	113	2.0[a]	2.0[a]	25[a]	63[a]	27[a]	87[a]	12[a]	18[a]
	114	3.0[a]	2.0[a]	27[a]	72[a]	24[ab]	85[a]	13[a]	13[a]
	299	2.0[a]	2.0[a]	23[a]	63[a]	11[c]	77[a]	12[a]	18[a]
	371	2.0[a]	2.0[a]	46[a]	69[a]	17[bc]	78[a]	11[a]	17[a]
	9001	2.0[a]	3.0[a]	34[a]	72[a]	25[ab]	98[a]	14[a]	17[a]
	9002	3.0[a]	3.0[a]	34[a]	94[a]	23[ab]	88[a]	14[a]	13[a]
Mean		**2.0**	**2.0**	**28**	**71**	**21**	**84**	**12**	**16**
Whole Stalk	113	2.0[a]	2.0[a]	26[a]	67[a]	33[a]	74[a]	12[a]	17[a]
	114	3.0[a]	2.0[a]	25[a]	69[a]	22[ab]	90[a]	14[a]	13[a]
	299	2.0[a]	2.0[a]	28[a]	67[a]	12[c]	81[a]	13[a]	22[a]
	371	2.0[a]	2.0[a]	26[a]	61[a]	18[bc]	71[a]	12[a]	19[a]
	9001	3.0[a]	2.0[a]	27[a]	64[a]	25[ab]	90[a]	16[a]	12[a]
	9002	3.0[a]	2.0[a]	35[a]	82[a]	28[ab]	100[a]	14[a]	10[a]
Mean		**2.0**	**3.0**	**30**	**68**	**22**	**84**	**13**	**16**

Note: Values within a column within planting scheme with the same letter are not significantly different at $P<0.05$.

Table 3.13. Nutrient uptake of cane stalk and leaves planted as whole stalk and billet, second ratoon (2015).

Planting Scheme	**Variety**	**Cu**		**Fe**		**Mn**		**Zn**	
		Stalk	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**	**Stalk**	**Leaf**
		---kg ha^{-1} DM---							
Billet	113	0.05^{ab}	0.02^{a}	0.55^{ab}	0.48^{a}	0.54^{a}	0.65^{a}	0.25^{a}	0.13^{ab}
	114	0.04^{b}	0.01^{a}	0.42^{b}	0.44^{a}	0.36^{ab}	0.52^{a}	0.20^{a}	0.08^{c}
	299	0.04^{b}	0.02^{a}	0.51^{b}	0.54^{a}	0.24^{b}	0.67^{a}	0.26^{a}	0.15^{a}
	371	0.06^{a}	0.02^{a}	1.03^{a}	0.63^{a}	0.41^{ab}	0.72^{a}	0.28^{a}	0.15^{a}
	9001	0.04^{b}	0.02^{a}	0.50^{b}	0.43^{a}	0.35^{ab}	0.59^{a}	0.21^{a}	0.10^{bc}
	9002	0.05^{ab}	0.02^{a}	0.61^{ab}	0.66^{a}	0.39^{ab}	0.62^{a}	0.24^{a}	0.10^{bc}
Mean		**0.05**	**0.02**	**0.63**	**0.54**	**0.39**	**0.64**	**0.25**	**0.12**
Whole Stalk	113	0.05^{ab}	0.02^{a}	0.57^{ab}	0.54^{a}	0.73^{a}	0.62^{a}	0.26^{a}	0.14^{bc}
	114	0.05^{ab}	0.02^{a}	0.44^{b}	0.51^{a}	0.38^{c}	0.67^{a}	0.24^{a}	0.10^{bc}
	299	0.06^{a}	0.05^{a}	0.76^{a}	0.53^{a}	0.32^{c}	0.64^{a}	0.34^{a}	0.17^{ab}
	371	0.06^{a}	0.02^{a}	0.68^{ab}	0.64^{a}	0.51^{ab}	0.74^{a}	0.31^{a}	0.19^{a}
	9001	0.04^{b}	0.02^{a}	0.44^{b}	0.43^{a}	0.40^{bc}	0.60^{a}	0.25^{a}	0.08^{c}
	9002	0.04^{b}	0.02^{a}	0.56^{ab}	0.65^{a}	0.46^{bc}	0.81^{a}	0.24^{a}	0.07^{c}
Mean		**0.05**	**0.03**	**0.60**	**0.56**	**0.47**	**0.68**	**0.28**	**0.13**

Note: Values within a column within planting scheme with the same letter are not significantly different at P<0.05.

3.4 Conclusions

The existing sugar cane industry in Louisiana is perceived as an advantage for biofuel industry because of the similarities of energy cane and sugarcane by way they are cultivated, harvested, and processed. Dedicated energy crops for second generation bioenergy production should be high yielding, fast growing, have low lignin content, and require relatively lower inputs for its growth and harvest. In this study, the effect of the type of planting material and variety on cane stalk and leaf dry matter yield, quality components, biomass chemical composition, nutrient concentration and uptake were evaluated. The level and quality of dry matter produced by cane was not affected by planting method. On average years, billet planting has more advantages over whole stalk planting and therefore billets can be a logical choice as planting material in energy cane production. In addition, the absence of differences in nutrient removal rate between whole stalk- and billet- planted cane suggests that the fertilizer recommendation will remain virtually the same for these two planting scheme. Considering the ease in planting and harvesting particularly under the condition of severe cane lodging and lack of labor availability, billet planting appears to be an option for the Louisiana energy cane production. More likely in the end, the availability of farm machineries and equipment, seeds, and labor will be the determining factors for adoption of planting method.

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Chapter 4. Relationship of Red and Red-Edge Reflectance-Based Vegetation Indices with Stalk and Fiber Yield of Energy Cane Harvested at Different Dates

4.1 Introduction

Yield estimation in crop production at national and regional scale has an important role on economy (Hayes and Decker, 1996; Prasad, 2006). Conventional methods of yield estimation are often complicated, costly, time-consuming and cannot be used in large-scale operation (Reynolds et al., 2000). Therefore there has been large research effort to develop cheaper and faster methods of crop yield estimation. Remote sensing technique has the capacity to capture spatial information of features and phenomena on earth on an almost real-time basis. Remote sensing technology is the acquisition of information about an object or phenomenon without making physical contact with the object using sensors (satellites, aircrafts, and ground-based sensors) (Lillesand et al., 2008). A sensor can be active or passive depending on the light source. Active sensors have their own source of light and can work independently with or without sunlight, while passive sensors do not have any light source and dependent on solar radiation or other artificial source of illumination (Aggarwal, 2004). In remote sensing technology, electromagnetic radiation reflected (e.g., visible light, near-infrared, etc.) from targets on the ground is normally used as an information carrier. Different materials reflect and absorbs differently at different wavelengths (Ashraf et al., 2011). Thus, the targets can be differentiated by their reflectance signatures as captured by the sensors. The amount of energy reflected from a surface is usually expressed as a percentage of the reflected to the amount of energy striking the objects. Reflectance is 100% if all of the light striking an object bounces back whereas reflectance is 0% if all light is transmitted or absorbed.

Many studies have shown high correlation between vegetation spectral index extracted from satellite images and green plant biomass. According to Groten (1993) these parameters can be combined to predict biomass accumulation. Vegetation has a unique spectral signature readily distinguishable from other types of land cover in an optical/near-infrared (NIR) image. Vegetation reflectance is low in both blue and red regions of the spectrum due to absorption by chlorophyll pigments. Reflectance peaks at the green region which gives rise to the green color of vegetation. In the NIR region, the reflectance is much higher than that in the visible band due to the cellular structure in the leaves (Ashraf et al., 2011). The shape of the reflectance spectrum can be used for identification of vegetation type, to calculate vegetation indices (VI) and to estimate yield potential (Unganai and Kogan, 1998; Labus et al., 2002; Prasad et al., 2006; Ren et al., 2008). Vegetation indices (VIs) are mathematical combinations or ratios of mainly red, green and infrared spectral bands; they are designed to find functional relationships between crop characteristics and remote sensing observations (Wiegand et al., 1990). The most widely used VIs are computed using data from the red and NIR portions of the electromagnetic spectrum (Treitz and Howarth, 1999). These VIs operate by contrasting intense chlorophyll pigment absorptions in the red against the high reflectance in the NIR (Hoffer, 1978; Elvidge and Chen, 1995; Todd et al., 1998).

Many VIs based on canopy spectral reflectance can be used to estimate crop physiological properties, including plant biomass and crop yield (Tucker, 1979; Raun et al., 2002; Zhao et. al., 2003). Simple ratio (SR), normalized difference vegetation index (NDVI), NDVI red-edge, and SR red-edge are VIs commonly use to predict biomass yield (Hansen and Schjoerring, 2003; Mutanga and Skidmore, 2004; Vina and Gitelson, 2005). Raun et al. (2005) established yield prediction model using NDVI in order to develop a nitrogen (N) algorithm for determination of plant N requirements on-a-need basis; this has been tested in corn (Z*ea mays*), wheat (*Triticum aestivum*), and cotton (*Gossypium hirsutum*) and showed potential in increasing crop N use efficiency (NUE) (Raun et al., 1999; Tubana et al., 2008).

However, a major limitation of using VIs particularly NDVI based on the red and NIR portion of the electromagnetic spectrum is that they asymptotically approach a saturation level after a certain biomass density or leaf area index (LAI) (Tucker, 1977; Sellers, 1985; Todd et al., 1998; Gao et al., 2000; Thenkabail et al., 2000). The NDVI provides poor estimates in areas where there is 100% vegetation cover and therefore, has limited value in assessing biomass during the peak growing season (Thenkabail et al., 2000). With this limitation, there is a need to enhance techniques that can accurately estimate a high biomass producing crop or more densely vegetated areas like energy cane (*Saccharum officinarum*). For this reason, it is vital to identify VIs which remain sensitive to canopy biophysical attributes (percent vegetation cover, green leaf biomass, and photosynthetic capacity) even at canopy closure for optical sensor-based yield prediction in energy cane.

With accuracy combined with speed, optical sensor-based yield prediction has profound role on timely implementation of effective management of N fertilizer and handling of feedstock during harvesting. Thus, this study was conducted to evaluate the relationship of spectral reflectance readings with millable stalk, N uptake, and lignocellulose yield of energy cane harvested at different dates and to identify VIs that can be used for energy cane millable stalk and lignocellulose yield prediction.

4.2 Materials and Methods

4.2.1 Site location, experimental design and layout

This study was established at the Louisiana State University AgCenter Sugar Research Station in St. Gabriel, Louisiana at 30º15'47''N 91º05'54''W. The soil was a Commerce silt loam (fine-silty, mixed, nonacid, thermic Aeric Fluvaquent). Before planting, composite soil samples werecollected for initial soil chemical analysis. The samples were dried and ground to pass a 2 mm-size sieve.. Carbon:nitrogen (C:N) ratio was determined using CN 91 analyzer (Model: Vario el cube; Manufacturer: Elementar). The soil had an initial pH value of 5.5 with C:N ratio of 6:1, and Mehlich-3 (Mehlich, 1984) extractable phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), and copper (Cu) content of 34, 170, 458, 10.8, and 3.5 mg kg^{-1}, respectively.

The plot size was 9.0 m wide by 1.83 m long containing three bedded rows. The length of the alley between plots was 3 m. The treatments included two energy cane varieties, Ho 02-113 and US 72-114 and four N application rates of 0, 56, 112, and 224 kg ha^{-1}. A 2 x 4 x 3 factorial design with a split-split plot arrangement were established where variety was designated as the main plot and N application rate as sub-plot, and replicated four times. Harvest date as sub-sub plot and was done three times for each cropping year.

4.2.2 Planting, fertilization and harvesting

Planting was accomplished on September 14, 2012 using billets as planting material. The billets were cut with a combine harvester with an average of 50-55 cm in length with approximately three buds per billet. Bedded rows with 1.8 m long segment were opened to plant 5 to 6 billets. In April, urea-ammonium nitrate (UAN; 32-0-0) solution with the rates of 0, 56, 112, and 224 kg N ha^{-1} was knifed-in near the shoulder of each bed at 15 cm depth. The amount of K was 60-80 kg ha^{-1} and no P was applied.

For each cropping year, fifteen plants were taken from the middle row of each plot and manually cut from the base at three sampling time: two- and one-month earlier than the harvest date, and at harvest; Table 4.1 showed the sampling and harvesting schedule of the cane stalks at St. Gabriel, Louisiana from 2013 to 2015 cropping year. The harvest dates varies every cropping year because it will depend on the cane age. Cane is planted once and regrows on the succeeding years. The traditional practice of harvesting plant cane, first ratoon, and second ratoon falls on the months of December, November, and October, respectively. At two-and one-month earlier sampling, the yield was computed based on the millable stalk population in order to get the total stalk weight per plot. At scheduled harvest, energy cane stalks were cut from each plot using a Case IH 8800 Series sugarcane harvester (Case IH Agriculture, Racine, WI) and loaded to wagon with load cell to determine the plot weight.

Table 4.1. Sampling and harvesting schedule of the cane stalks at St. Gabriel, Louisiana from 2013 to 2015 cropping.

Harvest Dates	**2013 Plant Cane**	**2014 First Ratoon**	**2015 Second Ratoon**
2-Months Earlier	October	September	August
1-Month Earlier	November	October	September
Scheduled Harvest	December	November	October

The fifteen plants were separated into stalks and leaves and weighed. Stalks were shredded and analyzed for sugar quality parameters (theoretical recoverable sugars - TRS, sucrose content, total soluble solids - Brix, and fiber content) using SpectraCane Near Infrared System (Bruker Coporation, Billerica, Massachusetts). Following this analysis, shredded stalks were dried at 60°C for more than 48 hours and ground to pass a 1-mm sieve, and analyzed for total N using CN 91 analyzer (Model: Vario el cube; Manufacturer: Elementar) and lignocellulosic composition using ANKOM^{2000} Filter Bag method. Ground stalk samples weighing 0.5 g was placed in ANKOM F57 filter bags and heat sealed and underwent a series of extractions for Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL). The residue after NDF extraction is predominantly composed of hemicellulose,

cellulose and lignin while the ADF extraction is composed of cellulose and lignin and ADL residue represents lignin. The different lignocellulosic composition was computed using difference method:

% Hemicellulose = % NDF – % ADF;

% Cellulose = % ADF – % ADL; and

% Lignin = % ADL

For this study, the hemicellulose and cellulose yield (hereafter termed as fiber yield) was used. Fiber yield was computed as = [% hemicellulose x stalk dry weight] + [%cellulose x stalk dry weight].

4.2.3 Sampling Area and Data Collection

Canopy reflectance readings were collected using Ocean Optics Jaz® hyperspectral spectrometer from 300 to 1100 nm with optical resolution at 1.5 nm. Before collecting canopy reflectance readings, both incident light (downwelling irradiance) and the outgoing light (upwelling) were determined from a 1 m^2 white steel plate coated with barium sulfate for correcting environmental noise interference. The distance between the fiber optic sensor and target (white plate or energy cane canopy) was determine to make sure that the field of view covered a 1 m^2 area (sampling area size). The distance between the energy cane canopy and fiber optic sensor was calculated based on the lens field of view by using trigonometry function. The cosine corrector and Gershun tube with 28 degree field of view was attached to the fiber optic sensor (Ocean Optics, Dunedin, FL). Since the field of view was 28 degree, the height required to cover 1 m^2 was computed by multiplying Tangent 14^o with the length of the adjacent side.

Three spots per row were flagged, a total of nine spots per plot. Reflectance readings were taken from each spot. These nine spots remained undisturbed for the entire crop growth duration wherein reflectance readings were taken at least twice a month from 4 weeks after N (WAN) application until 16 weeks after N application (Table 4.2).

Table 4.2. Schedule of collecting energy cane canopy spectral reflectance reading at St. Gabriel, Louisiana from 2013 to 2015.

Year/Crop	**Fertilization**	**Month/Week after N (WAN) application**							
		May		June		July		August	
2013 Plant Cane	April 26	3	4	6	8	10	13	-	-
2014 First Ratoon	May 6	-	-	4	6	8	11	14	16
2015 Second Ratoon	May 6	-	-	4	6	9	11	-	-

4.2.4 Spectral Reflectance and Its Indices

Three bands were selected for basic spectra reflectance, the selection of these wavebands were based on the previous studies conducted by Kanke (2013) and Chanda (2015). Reflectance of 15 nm width was averaged and used as a point value of reflectance.

ρ_{red} = 668 – 673nm

$\rho_{red\text{-}edge}$ = 703 – 708nm

$\rho_{near\text{-}infrared}$ = 778 – 782nm

The following VIs were computed; SRred, SRred-edge, NDVIred, and NDVIred-edge.

a. **Simple ratio (SR)**: It is one of the old spectral VIs. It is computed using the following formula:

$$SR_{red} = \frac{\rho_{NIR}}{\rho_{red}}$$ (Jordan, 1969; Ritchie, 2003)

Where, ρ_{NIR} is the reflectance at 780 nm and ρ_{red} is the reflectance at 670 nm

Simple ratio is the ratio between the reflectance at the NIR and red bands, the value of SR ranges from 1 to 30. For bare soil, the value tends to be 1 since the reflection is nearly similar at red and NIR bands. As the greenness or chlorophyll content of plants increases, the SR value increases.

b. Red-edge simple ratio index: This is a modification of the SR index which uses red-edge reflectance. It is computed using the following formula:

$$SR_{red\text{-}edge} = \frac{\rho_{NIR}}{\rho_{red-edge}} \text{ (Sims and Gamon, 2002)}$$

Where, $\rho_{red-edge}$ is the reflectance at 705 nm. Red-edge is the sharp increase of reflection between the red wavebands to the NIR wavebands.

c. Normalized difference vegetation index (NDVI): It is computed using the following formula:

$$NDVI_{red} = \frac{\rho_{NIR}-\rho_{red}}{\rho_{NIR}+\rho_{red}} \text{ (Rouse et al., 1973)}$$

The value of NDVI generally ranges from -1 to +1 and specifically ranges from 0.2 to 0.8 for normal vegetation, negative values for water and around 0 for bare soil. Healthy plants with dense canopy give an NDVI value near 1.

d. Red-edge normalized difference vegetation index (NDVIred-edge): For this modification of NDVI, measurements were obtained using reflectance at NIR and red-edge regions. It is computed using the following formula:

$$NDVI_{red\text{-}edge} = \frac{\rho_{NIR}-\rho_{red-edge}}{\rho_{NIR}+\rho_{red-edge}} \text{ (Sims and Gamon, 2002)}$$

4.2.5 Data Analysis

Statistical analysis was performed using SAS 9.4 (SAS Institute, 2012) for Pearson correlation analysis while Excel software was used for regression analysis. Regression analysis was performed to determine the relationship between vegetation indices and millable stalk yield, amount of cellulose and hemicellulose and harvest dates. Pearson correlation was performed to determine the significant effect of millable stalk yield, N uptake, and amount of cellulose and hemicellulose with VIs at different harvest dates.

4.2.6 Climatic Condition

Monthly average precipitation (bar graph) and cumulative growing degree days (CGDD – line graph) for three years (2013, 2014, and 2015) are presented in Figure 4.1. In terms of total rainfall per year, 2013 and 2015 had similar amount of rainfall received with a total of 1720 mm while 2014 only had 1430 mm. In terms of CGDD, 2015 cropping year obtained the highest CGDD than 2014 and 2013 cropping years particularly on the months of May, June, July and August.

Cumulative growing degree days are calculated from the average centigrade temperature of each day over a time period-usually from beginning of the calendar year to the last sensing date. Here are the steps to follow in this calculation:

1. Obtain daily Fahrenheit maximum and minimum temperatures from beginning of the calendar year to the last sensing date.
2. Convert these temperatures to centigrade (C) degrees from Fahrenheit (F) degrees with this formula C = 5/9 (F-32).
3. Calculate the average centigrade temperature for each day with the formula

   Average = (max + min)/2.
4. Add together all of the positive values from beginning of the calendar year to the last sensing date to obtain the cumulative GDD's.

   $CGDD = ((Temp_{max} + Temp_{min})/2) – \text{base temperature})$ (Barger, 1969)

Where:

$Temp_{max}$ = maximum daily temperature

$Temp_{min}$ = minimum daily temperature

Base temperature = 18°C for sugarcane production

Cumulative growing degree days are a measure of the amount of warmth that plants have experienced over the past time. The warmer it is, the faster the plant will develop.

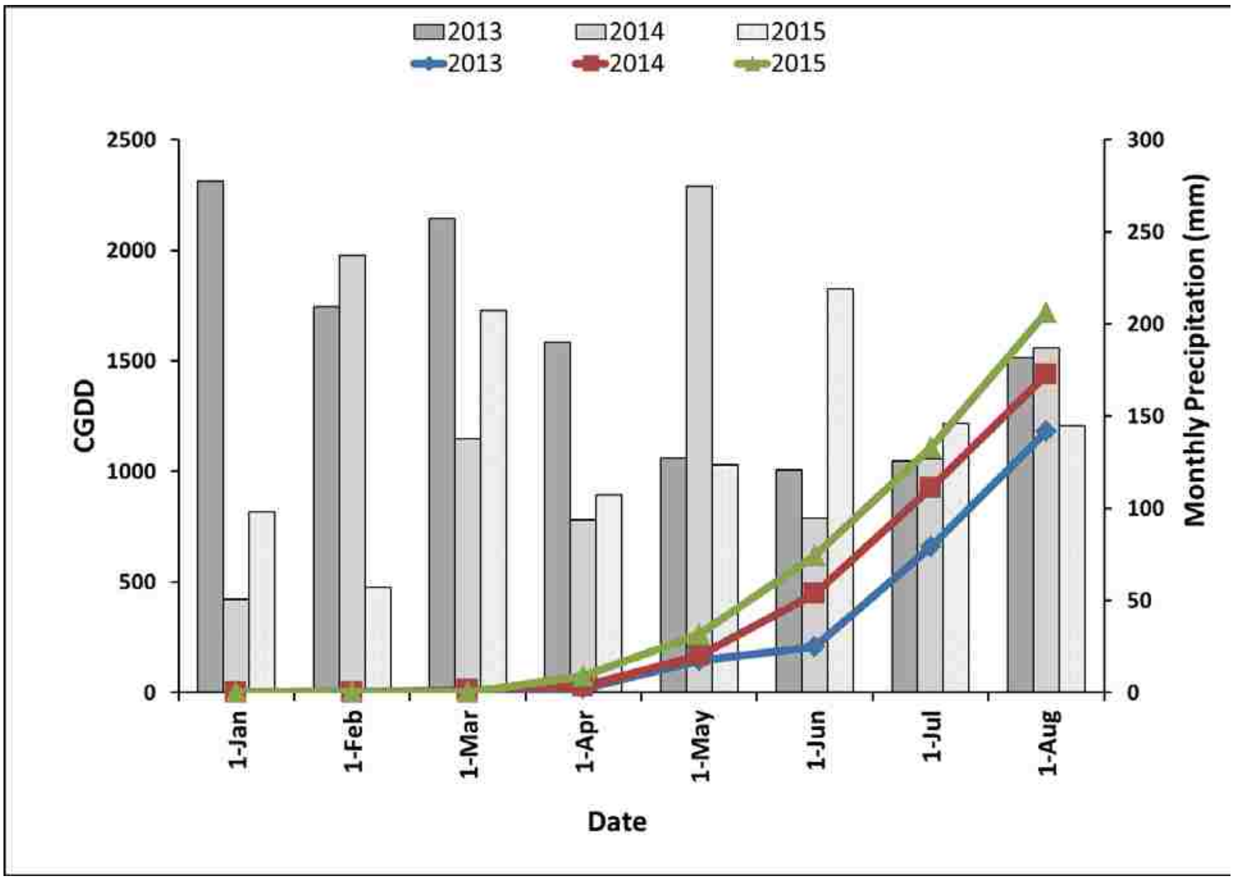

Figure 4.1. Cumulative growing degree days (CGDD) and monthly rainfall distribution from beginning of year and during the sampling period (spectral reflectance reading) at St. Gabriel, LA 2013-2015.

4.3 Results and Discussions

4.3.1. Relationship of VIs with Energy Cane Stalk Yield and N Uptake

The result of this study showed that SR and NDVI computed from reflectance readings at wavebands 670 nm (red) and 705 nm (red-edge) consistently had linear relationship with stalk yield across harvest dates and cane age (Table 4.3). Similar findings were reported by Kanke (2013) and Kanke et al. (2016) on sugarcane and rice (*Oryza sativa*). In their work, the red-edge-based VIs had a stronger degree of linear relationship with biomass, N uptake, and grain yield of rice compared with red-based VIs. This was also the case in a study conducted by Mutanga and Skidmore (2004) wherein the highest correlation of biomass with VIs was obtained from those computed from red-edge band. The red-edge denotes a region of transition from strong chlorophyll absorption to NIR reflectance. The shorter wavelengths (700-750 nm) of the red-edge portion are sensitive to changes in chlorophyll content (Felella and Penuelas, 1994; Lichtenthaler et al., 1996) while longer wavelengths (750-800 nm) of the red-edge portion, multiple scattering from leaf layers results in higher reflectance (Kumar et al., 2001). This revealed strong correlations between the red-edge and LAI or biomass (Filella and Penuelas, 1994; Todd et al., 1998; Blackburn and Pitman, 1999; Clevers et al., 2000).

In this study, it is notable that across sampling time and year, VIs computed from red-edge almost consistently had higher association with stalk than the red-based VIs based on Pearson correlation analysis (Table 4.3). Based on sensing time, SR and NDVI computed from both red and red-edge reflectance readings obtained higher correlation coefficient (*r*) with stalk yield at 6 and 8 weeks after N (WAN) application for the 2013 plant cane, 14 WAN for the 2014 first ratoon, and 6, 9, and 11WAN for the 2015 second ratoon (Table 4.3). The collection of sensor readings did not fall on the same number of weeks after N application for all the cropping years due to interference of rainfall (Table 4.2).

There were significant linear relationships between VIs and millable stalk yield of energy cane harvested at different dates from 2013, 2014, and 2015 cropping years (Table 4.3). For 2013, the correlation of SR and NDVI with stalk yield was higher at 6 and 8 WAN application compared at 10 WAN application for the three harvest dates. For 2014, the *r* values between stalk yield and VIs were higher at 14 WAN application than at 6 and 8 WAN application whereas in 2015, significant *r* (0.59 – 0.78) between stalk yield and VIs was observed only for energy cane that were harvest one-month earlier (September) and at scheduled harvest date (October). The linear relationship of VIs and stalk N uptake was evaluated (Table 4.4). In 2013 plant cane, there were only few sensing dates from which the computed VIs obtained significant positive linear relationship with stalk N uptake, all of them were red-edge based VIs. There were a few cases where *r* values were negative however, these were not significant. It was notable also that these were only observed for cane harvested two months earlier (October) than the scheduled harvest date (December). On the other hand in 2014 and 2015 ratoon crops, regardless of sensing and harvest dates, all VIs and stalk N uptake obtained significant positive linear relationship. The *r* values of red-edge based VIs with stalk N uptake were generally higher than the red-based VIs.

The outcomes of the Pearson correlation analysis suggest a strong dependence between VIs and stalk yield; for N uptake, it was only evident in ratoon crops (2014 and 2015). Regression analysis was conducted to determine if the relationship of VIs with stalk yield and N uptake can be described using a linear model. Initially, the data was pooled to evaluate the feasibility of having a generalized model applicable across crop age for predicting stalk yield and

N uptake based on the different VIs used in this study. The resulting coefficient of determination (r^2) values were low thus, the regression analysis was done separately for each harvest time of each year.

For 2013 plant cane, sensing started at 3 WAN until 13 WAN application (May 15, 2013 to July 25, 2013) but further sensing was not feasible due to lodging. The results showed that the r^2 between stalk yield and VIs (SRred, SRred-edge, NDVIred and NDVIred-edge) at 3 WAN application was low (<0.10) for the three harvest dates. This weak relationship could be potentially due to very small ground coverage of energy cane biomass. At this early stage of growth, the CGDD was low combined with low N uptake which led to slow growth and low biomass accumulation. Kwong and Deville (1994) reported that fertilizer N accumulation in sugarcane was low prior to a period of rapid N uptake, approximately 140 to 150 days after previous harvest.

Vegetation indices computed from sensor readings collected at 6 and 8 WAN applications (June, 2013) showed better linear relationship with millable stalk yield compared to VIs at 10 WAN application (July) (Table 4.6). Results showed that the r^2 between stalk yield and SRred, SRred-edge, NDVIred and NDVIred-edge obtained the highest value of 0.43, 0.46, 0.36, and 0.43, respectively at 8 WAN under the scheduled harvest date. The r^2 between stalk yield and SRred, SRred-edge, NDVIred and NDVIred-edge tended to decrease with sampling time, i.e. from 10 to 13 WAN application. All of the VIs measured from 6 to 10 WAN application did not yield r^2 values higher than 0.20 with N uptake across harvest dates (Table 4.7). One of the important ideas developed over the past years was that plant development can be described and followed quantitatively by the number of leaves, tillers, and roots. This development under field conditions can be described using CGDD. Plants require a specific amount of heat to develop from one stage to another. Research has shown that measuring the heat accumulated over time provides a more accurate physiological estimate than counting calendar days. The ability to predict a specific crop stage permits better N management. For the duration of the 2013 cropping year, CGDD from beginning of the year (January 2013) to sensing (June 2013) was 645 as shown in Figure 4.1. According to Lofton et al. (2012) they found out that the strongest relationship between VIs and sugarcane yield occurred when the CGDD was between 601 to 751. This timeframe corresponded to the last week in May to the first week in June for all cropping years (2008-2011). The relationship between spectral reflectance values and sugarcane yield after 751 CGDD substantially decreased.

Several studies showed that the incorporation of GDD in yield prediction model for other crops resulted in improved r^2. Raun et al. (2002) and Lukina et al. (2000) showed strong relationship between NDVI and grain yield in winter wheat when NDVI readings were adjusted using GDD ($r^2 = 0.83$, $P < 0.01$) for in-season estimate of yield (INSEY), this crop stage was between Feekes 4 to 6. On the other hand, Teal et al. (2006) found that the optimum growth stage for predicting corn yield was at the eight leaf vegetative phase, or between 800–1,000 GDD. For this study, normalizing VIs using CGDD did not improve its relationship with stalk yield. However it can be used to determine if the amount of biomass production optimal for sensing is approaching.

For 2014 first ratoon cropping, sensor reading was done at 4 WAN to 16 WAN application (June 2, 2014 to August 25, 2014). Fertilization was done late (May 6, 2014) due to rainfall interference (Figure 4.1). Unlike in 2013, the strongest linear relationship of VIs with millable stalk yield and N uptake was obtained at 14 WAN applications (August 13, 2014) (Tables 4.6 and 4.7). Results revealed that the r^2 between stalk yield and VIs (SRred, SRred-edge, NDVIred and NDVIred-edge) obtained the highest values of 0.57, 0.55, 0.54, 0.54, respectively, for the scheduled harvest. Lower r^2 values were obtained for N uptake, but just like millable stalk yield, these values were generally the highest at scheduled harvest and at 14 WAN application. As previously observed, SR and NDVI both red and red-edge-based have similar r^2 values. This suggests that SR and NDVI at red and red-edge can be good estimates of energy cane yield potential even at high biomass accumulation. This outcome was similar with the 2015 second ratoon wherein it showed a consistent linear relationship between millable stalk yield and VIs measured from 6 to 11 WAN applications (Table 4.6). The highest r^2 was obtained at 6 WAN application for SR and NDVI (both red and red-edge based) when stalk was harvested one-month earlier (r^2 ~ 0.60). This was almost the same r^2 value when millable stalk was harvested at scheduled harvest date (r^2 = 0.58). The N uptake in 2015 yielded the highest r^2 with red- and red-edge-based SR and NDVI for cane harvested one month earlier. Across sensing dates, all VIs measured at 6 WAN application consistently obtained r^2 values>0.5.

Several reports have shown a similar trends, where the relationship between NDVI and yield increased as the crop developed (Begue et al., 2010; Begue et al., 2008; Simoes et al., 2005). Rao et al. (2002) also reported that the correlation between NDVI and sugarcane yield increased throughout rapid growth until the end of the grand growth stage.

4.3.2. Relationship of VIs with Fiber Yield

Energy cane is mainly produced for fiber. Another objective of this study was to evaluate the feasibility of estimating as fiber yield of energy cane harvested at different dates. Pearson correlation and regression analyses were performed between VIs and fiber yield. Results showed that there was a statistically significant linear relationship between VIs and fiber yield of cane harvested at different dates across cropping years (Table 4.5). However for 2013, significant correlation (0.47 – 0.52) between fiber yield and VIs was only observed at 6 WAN application and only for cane harvested two months earlier. For 2014 and 2015 cropping years, VIs collected at 6 and 14 WAN application obtained good correlation with fiber yield with *r* values ranging from 0.75-0.80 and 0.53-0.70, respectively. Better correlation between VIs and fiber yield was obtained for cane harvested at scheduled date. It was notable that VIs collected at 6 WAN application consistently yielded *r* values >0.80 with fiber yield.

As expected, the results of regression analysis between these parameters in 2013 did not yield r^2 values higher than 0.28 (Table 4.8). The r^2 between fiber yield and VIs (SR and NDVI) were highest at 14 WAN (0.44 – 0.49) and 6 WAN (~0.57) application for 2014 and 2015, respectively. While cane harvested one-month earlier also showed a better r^2 between VIs and fiber yield, it was only evident for the 2015 cropping year. Overall, these outcomes suggest that VIs can estimate fiber yield better for cane harvested at scheduled date. Perhaps this indicates that the applicability and accuracy of fiber yield estimation largely relies on cane maturity.

Harvest date (across varieties and crop age) significantly affected cellulose and hemicellulose composition of stalk where in most cases the highest yield was recorded for cane harvested at scheduled date (data not shown). In addition, the moisture content of leaves may have affected the amount of reflected light from the red and red-edge bands. Studies conducted by Curran (1989), Elvidge (1990), Wessman (1990), and Kokaly (2001) showed that dried leaf has three absorption features centered near 1.7, 2.1, and 2.3 μm. However in the fresh leaf's spectrum, these were not easily discernible. These three features are caused by several leaf biochemical constituents, the most abundant and widely studied of which are N (in proteins), cellulose and lignin. As leaves and plants vary in the concentration of these constituents, their reflectance spectra vary by changing strengths of the related absorption features.

4.3.3. Application of Estimating Millable Stalk and Fiber Yield using VIs Measured Early in the Season

There was no significant linear relationship between millable stalk yield and VIs when data was pooled across crop age. This indicates that the development of generalized yield prediction model for energy cane (both stalk and fiber) will be limited by crop age. For future research which will be designed to develop a generalized yield prediction model, building a large database combined with data transformations (e.g. incorporation of GDD, adjusting NDVI based on crop age) are essential. Thus far, this study demonstrated the feasibility of using VIs collected between 6 and 9 WAN application as estimates of stalk yield of cane harvested at scheduled dates (Table 4.9). These periods fell approximately between June to mid-July which was considered outside the timeframe of N application and perhaps of limited use for N fertilizer management. The VIs collected later in the season (11 to 14 WAN, approximately mid-July to August) can be used for yield estimation that can provide information for a more efficient handling of feedstock. For fiber yield estimation, the possibility seems limited for ratoon crops but can be done for VIs collected as early as 6 WAN application. This study revealed several limitations and strengths of optical sensing technology as tool for yield prediction in energy cane production. This information can provide insights on several factors (e.g. optimal sensing date, SR vs. NDVI, red vs. red-edge) so that future research can focus on areas in optical sensing technology that will ensure success to yield useful outcomes.

Table 4.3. Pearson correlation coefficient (*r*) between millable stalk yield of energy cane and vegetation indices from 2013 – 2015, St. Gabriel, LA.

Year/Crop	**Vegetation Indices (VIs)**	**Weeks after N (WAN) application**	**Two-Months Earlier Harvesting**	**One-Month Earlier Harvesting**	**Scheduled Harvest**
2013, Plant Cane	SR_{red}	6	0.54**	0.48**	0.59**
		8	0.38*	0.54**	0.65**
		10	0.28	0.25	0.27
	$SR_{red-edge}$	6	0.59**	0.57**	0.67**
		8	0.45**	0.57**	0.68**
		10	0.34	0.35*	0.38*
	$NDVI_{red}$	6	0.51**	0.46**	0.58**
		8	0.36*	0.55*	0.60**
		10	0.24	0.22	0.25
	$NDVI_{red-edge}$	6	0.55**	0.53**	0.63**
		8	0.43**	0.59**	0.65**
		10	0.31	0.34	0.36*
2014, First Ratoon	SR_{red}	6	0.41*	0.41*	0.61**
		8	0.44*	0.55**	0.58**
		14	0.55**	0.55**	0.76**
	$SR_{red-edge}$	6	0.43*	0.42*	0.60**
		8	0.41*	0.50**	0.55**
		14	0.55**	0.58**	0.74**
	$NDVI_{red}$	6	0.44*	0.41*	0.60**
		8	0.26	0.42*	0.35*
		14	0.53**	0.54**	0.74**
	$NDVI_{red-edge}$	6	0.45**	0.42*	0.59**
		8	0.34	0.46*	0.46**
		14	0.56**	0.58**	0.74**
2015, Second Ratoon	SR_{red}	6	0.37	0.77**	0.76**
		9	0.37	0.65**	0.72**
		11	0.39	0.67**	0.73**
	$SR_{red-edge}$	6	0.36	0.78**	0.76**
		9	0.37	0.65**	0.75**
		11	0.39	0.65**	0.77**
	$NDVI_{red}$	6	0.36	0.73**	0.77**
		9	0.39	0.62**	0.71**
		11	0.30	0.59**	0.64**
	$NDVI_{red-edge}$	6	0.35	0.75**	0.76**
		9	0.39	0.64**	0.75**
		11	0.34	0.62**	0.72**

Note: * p = 0.05; ** p = 0.001

Table 4.4. Pearson correlation coefficient (*r*) between N uptake energy cane stalk and vegetation indices from 2013 – 2015, St. Gabriel, LA.

Year/Crop	Vegetation Indices (VIs)	Weeks after N (WAN) application	Two-Months Earlier Harvesting	One-Month Earlier Harvesting	Scheduled Harvest
2013, Plant Cane	SR_{red}	6	0.21	-0.24	-0.29
		8	0.34	0.12	0.04
		10	0.18	0.11	0.04
	$SR_{red\text{-}edge}$	6	0.37*	-0.10	-0.17
		8	0.45*	0.16	0.09
		10	0.37*	0.22	0.13
	$NDVI_{red}$	6	0.23	-0.17	-0.28
		8	0.34	0.14	0.09
		10	0.26	0.16	0.07
	$NDVI_{red\text{-}edge}$	6	0.37*	-0.06	-0.15
		8	0.45*	0.17	0.13
		10	0.40*	0.23	0.14
2014, First Ratoon	SR_{red}	6	0.57**	0.64**	0.67**
		8	0.61**	0.72**	0.66**
		14	0.59**	0.56**	0.60**
	$SR_{red\text{-}edge}$	6	0.60**	0.67**	0.69**
		8	0.62**	0.72**	0.68**
		14	0.66**	0.68**	0.71**
	$NDVI_{red}$	6	0.55**	0.62**	0.64**
		8	0.36*	0.55**	0.46*
		14	0.55**	0.55**	0.59**
	$NDVI_{red\text{-}edge}$	6	0.58**	0.65**	0.65**
		8	0.50**	0.64**	0.58**
		14	0.65**	0.68**	0.69**
2015, Second Ratoon	SR_{red}	6	0.53**	0.78**	0.73**
		9	0.51**	0.72**	0.69**
		11	0.57**	0.70**	0.64**
	$SR_{red\text{-}edge}$	6	0.55**	0.79**	0.74**
		9	0.56**	0.74**	0.73**
		11	0.63**	0.71**	0.69**
	$NDVI_{red}$	6	0.53**	0.72**	0.67**
		9	0.51**	0.64**	0.63**
		11	0.50**	0.62**	0.54**
	$NDVI_{red\text{-}edge}$	6	0.54**	0.75**	0.69**
		9	0.55**	0.69**	0.69**
		11	0.58**	0.67**	0.63**

Note: * p = 0.05; ** p = 0.001

Table 4.5. Pearson correlation coefficient (*r*) between hemicellulose and cellulose content of energy cane and vegetation indices from 2013 – 2015, St. Gabriel, LA.

Year/Crop	**Vegetation Indices (VIs)**	**Weeks after N (WAN) application**	**Two-Months Earlier Harvesting**	**One-Month Earlier Harvesting**	**Scheduled Harvest**
2013, Plant Cane	SR_{red}	6	0.48*	0.08	0.18
		8	0.21	0.19	0.24
		10	0.09	0.06	0.21
	$SR_{red\text{-}edge}$	6	0.47*	0.12	0.26
		8	0.26	0.18	0.26
		10	0.13	0.08	0.23
	$NDVI_{red}$	6	0.45*	0.06	0.21
		8	0.22	0.26	0.25
		10	0.08	0.06	0.20
	$NDVI_{red\text{-}edge}$	6	0.43*	0.11	0.27
		8	0.25	0.23	0.28
		10	0.12	0.09	0.22
2014, First Ratoon	SR_{red}	6	0.43*	0.41*	0.49*
		8	0.47*	0.50**	0.55**
		14	0.49*	0.53**	0.72**
	$SR_{red\text{-}edge}$	6	0.47*	0.41*	0.48*
		8	0.46*	0.45*	0.50*
		14	0.54**	0.56**	0.69**
	$NDVI_{red}$	6	0.46*	0.42*	0.48*
		8	0.30*	0.36*	0.32*
		14	0.46*	0.51**	0.69**
	$NDVI_{red\text{-}edge}$	6	0.49*	0.42*	0.47*
		8	0.39*	0.40*	0.40*
		14	0.54**	0.55**	0.67**
2015, Second Ratoon	SR_{red}	6	0.52**	0.78**	0.82**
		9	0.49*	0.70**	0.65**
		11	0.56**	0.69**	0.63**
	$SR_{red\text{-}edge}$	6	0.51**	0.78**	0.83**
		9	0.51**	0.70**	0.67**
		11	0.57**	0.69**	0.66**
	$NDVI_{red}$	6	0.51**	0.73**	0.82**
		9	0.53**	0.63**	0.67**
		11	0.47*	0.61**	0.63**
	$NDVI_{red\text{-}edge}$	6	0.50**	0.74**	0.82**
		9	0.53**	0.66**	0.69**
		11	0.52**	0.65**	0.67**

Note: * p = 0.05; ** p = 0.001

Table 4.6. The relationship of SR and NDVI measured at 6 to 14 WAN application with millable stalk yield harvested at different dates and year.

Year/Crop	Vegetation Indices (VIs)	Weeks after N (WAN) application	Two-Months Earlier Harvesting		One-Month Earlier Harvesting		Scheduled Harvest	
2013, Plant Cane	SR_{red}	6	y = 1.54x + 17	r^2 = 0.29	y = 1.44x + 18	r^2 = 0.23	y = 1.58x + 16	r^2 = 0.35
		8	y = 1.23x + 17	r^2 = 0.15	y = 1.81x + 13	r^2 = 0.29	y = 1.96x + 9.45	r^2 = 0.43
	$SR_{red-edge}$	6	y = 5.31x + 10	r^2 = 0.35	y = 5.33x + 11	r^2 = 0.32	y = 5.57x + 8.11	r^2 = 0.44
		8	y = 3.76x + 13	r^2 = 0.20	y = 5.06x + 8.09	r^2 = 0.33	y = 5.34x + 5.12	r^2 = 0.46
	$NDVI_{red}$	6	y = 51.7x - 10	r^2 = 0.26	y = 49.0x - 7.30	r^2 = 0.21	y = 54.7x - 13	r^2 = 0.34
		8	y = 54.0x - 15	r^2 = 0.13	y = 87.04x - 40	r^2 = 0.30	y = 84.2x - 39	r^2 = 0.36
		10	y = 42.9x - 7.63	r^2 = 0.06	y = 42.5x - 6.32	r^2 = 0.05	y = 42.4x - 7.93	r^2 = 0.06
	$NDVI_{red-edge}$	6	y = 48.5x + 2.14	r^2 = 0.30	y = 49.3x + 2.70	r^2 = 0.29	y = 51.9x - 0.52	r^2 = 0.40
		8	y = 46.2x + 0.44	r^2 = 0.18	y = 66.9x + 11	r^2 = 0.35	y = 65.8x - 12	r^2 = 0.43
		10	y = 34.1x + 6.60	r^2 = 0.09	y = 39.2x + 4.23	r^2 = 0.11	y = 37.7x + 3.45	r^2 = 0.13
2014, First Ratoon	SR_{red}	6	y = 0.71x + 11	r^2 = 0.17	y = 0.80x + 14	r^2 = 0.17	y = 1.04x + 13	r^2 = 0.37
		8	y = 0.45x + 11	r^2 = 0.19	y = 0.64x + 12	r^2 = 0.30	y = 0.58x + 14	r^2 = 0.33
		14	y = 1.35x - 0.72	r^2= 0.31	y = 1.53x + 0.50	r^2 = 0.31	y = 1.83x - 1.95	r^2 = 0.57
	$SR_{red-edge}$	6	y = 2.08x + 8.84	r^2 = 0.19	y = 2.30x + 12	r^2 = 0.17	y = 2.87x + 11	r^2 = 0.36
		8	y = 1.36x + 9.50	r^2 = 0.17	y = 1.89x + 10	r^2 = 0.25	y = 1.82x + 12	r^2 = 0.31
		14	y = 3.56x - 0.20	r^2 = 0.30	y = 4.26x + 0.10	r^2 = 0.34	y = 4.78x - 0.93	r^2 = 0.55
	$NDVI_{red}$	6	y = 27.1x - 3.81	r^2 = 0.19	y = 29.2x - 1.70	r^2 = 0.17	y = 36.9x - 6.11	r^2 = 0.36
		8	y = 18.6x + 1.05	r^2 = 0.07	y = 34.1x - 8.32	r^2 = 0.17	y = 25.2x + 0.57	r^2 = 0.12
		14	y = 121x - 87	r^2 = 0.28	y = 141x - 100	r^2 = 0.30	y = 168x - 121	r^2 = 0.54
	$NDVI_{red-edge}$	6	y = 22.7x + 3.96	r^2 = 0.20	y = 24.4x + 6.67	r^2 = 0.18	y = 29.8x + 5.05	r^2 = 0.35
		8	y = 19.7x + 3.64	r^2 = 0.12	y = 29.9x + 0.54	r^2 = 0.21	y = 26.4x + 4.33	r^2 = 0.21
		14	y = 59.9x - 22	r^2 = 0.31	y = 71.1x - 26	r^2 = 0.34	y = 78.9x - 29	r^2 = 0.54
2015, Second Ratoon	SR_{red}	6	y = 0.52x + 9.42	r^2 = 0.14	y = 1.97x + 6.60	r^2 = 0.60	y = 14.5x + 13	r^2 = 0.58
		9	y = 0.34x + 10	r^2 = 0.14	y = 1.05x + 9.09	r^2= 0.42	y = 0.97x +13	r^2 = 0.51
		11	y = 0.36x + 8.85	r^2 = 0.15	y = 1.07x + 7.12	r^2 = 0.45	y = 0.98x + 11	r^2 = 0.53
	$SR_{red-edge}$	6	y = 1.31x + 8.57	r^2 = 0.13	y = 5.16x + 2.76	r^2 = 0.62	y = 3.82x + 10	r^2 = 0.58
		9	y = 1.03x + 8.54	r^2 = 0.14	y = 3.17x + 5.71	r^2 = 0.43	y = 3.05x + 9.36	r^2 = 0.57
		11	y = 1.19x + 7.56	r^2 = 0.16	y = 3.43x + 3.86	r^2 = 0.42	y = 3.41x + 7.04	r^2 = 0.60
	$NDVI_{red}$	6	y = 14.8x + 2.26	r^2= 0.13	y = 54.8x - 19	r^2 = 0.54	y = 43.9x - 8.49	r^2 = 0.59
		9	y = 20.6x - 3.41	r^2 = 0.15	y = 56.8x - 26	r^2 = 0.38	y = 55.1x - 21	r^2 = 0.51
		11	y = 19.4x - 2.89	r^2 = 0.09	y = 66.3x - 35	r^2 = 0.35	y = 59.1x - 26	r^2 = 0.41
	$NDVI_{red-edge}$	6	y = 11.8x + 6.85	r^2 = 0.12	y = 46.2x - 3.82	r^2 = 0.57	y = 35.5x + 4.68	r^2 = 0.58
		9	y = 15.8x + 3.39	r^2 = 0.15	y = 45.6x - 8.13	r^2 = 0.41	y = 45.1x + 4.72	r^2 = 0.57
		11	y = 16.1x + 2.99	r^2 = 0.12	y = 51.3x - 12	r^2 = 0.39	y = 49.8x - 8.38	r^2 = 0.52

Table 4.7. The relationship of SR and NDVI measured at 6 to 14 WAN application with stalk N uptake and vegetation indices from 2013 – 2015, St. Gabriel, LA.

Year/Crop	Vegetation Indices (VIs)	Weeks after N (WAN) application	Two-Months Earlier Harvesting		One-Month Earlier Harvesting		Scheduled Harvest	
2013, Plant Cane	$SR_{red-edge}$	6	y = 10.8x + 16	r^2 = 0.13	y = -4.77x + 79	r^2 = 0.01	y = -3.66x + 66	r^2 = 0.03
		8	y = 12.3x + 2.14	r^2 = 0.20	y = 6.70x + 34	r^2 = 0.02	y = 1.86x + 45	r^2 = 0.01
		10	y = 1.24x + 39	r^2 = 0.03	y = 1.18x + 48	r^2 = 0.01	y = 0.18x + 51	r^2 = 0.001
	$NDVI_{red-edge}$	6	y = 107x - 4.20	r^2 = 0.14	y = -26.2x + 77	r^2 = 0.003	y = -32.2x + 71	r^2 = 0.02
		8	y = 160x - 43	r^2 = 0.20	y = 94.9x + 5.08	r^2 = 0.03	y = 33.4x + 33	r^2 = 0.12
		10	y = 146x - 39	r^2 = 0.16	y = 129x - 20	r^2 = 0.05	y = 38.9x + 28	r^2 = 0.02
2014, First Ratoon	SR_{red}	6	y = 4.45x + 15	r^2 = 0.32	y = 5.29x + 16	r^2 = 0.41	y = 5.82x + 23	r^2 = 0.45
		8	y = 2.83x + 13	r^2 = 0.38	y = 3.51x + 12	r^2 = 0.52	y = 3.41x + 24	r^2 = 0.44
		14	y = 6.46x - 32	r^2 = 0.34	y = 6.48x - 24	r^2 = 0.31	y = 7.37x - 25	r^2 = 0.36
	$SR_{red-edge}$	6	y = 13.1x + 1.69	r^2 = 0.36	y = 15.5x + 0.97	r^2 = 0.45	y = 16.5x + 7.56	r^2 = 0.46
		8	y = 9.32x + 1.96	r^2 = 0.38	y = 11.4x - 0.93	r^2 = 0.52	y = 11.3x + 10	r^2 = 0.46
		14	y = 19.4x - 41	r^2 = 0.44	y = 20.9x - 40	r^2 = 0.46	y = 23.0x - 39	r^2 = 0.50
	$NDVI_{red}$	6	y = 153x - 64	r^2 = 0.30	y = 182x - 78	r^2 = 0.38	y = 199x - 80	r^2 = 0.40
		8	y = 119x - 49	r^2 = 0.13	y = 188x - 99	r^2 = 0.30	y = 167x - 70	r^2 = 0.21
		14	y = 571x - 436	r^2 = 0.30	y = 600x - 453	r^2 = 0.30	y = 678x - 508	r^2 = 0.34
	$NDVI^{red-edge}$	6	y = 132x - 23	r^2 = 0.33	y = 157x - 28.1	r^2 = 0.42	y = 165x - 23	r^2 = 0.42
		8	y = 129x - 35	r^2 = 0.24	y = 177x - 58	r^2 = 0.41	y = 168x - 41	r^2 = 0.33
		14	y = 318x - 154	r^2 = 0.42	y = 349x - 166	r^2 = 0.46	y = 377x - 174	r^2 = 0.48
2015, Second Ratoon	SR_{red}	6	y = 5.26x + 3.40	r^2 = 0.29	y = 11.9x - 14	r^2 = 0.60	y = 7.63x + 16	r^2 = 0.53
		9	y = 3.13x + 9.59	r^2 = 0.26	y = 6.57x - 2.42	r^2 = 0.51	y = 5.13x + 14	r^2 = 0.47
		11	y = 3.51x - 0.38	r^2 = 0.33	y = 6.39x - 11	r^2 = 0.49	y = 5.13x + 14	r^2 = 0.47
	$SR_{red-edge}$	6	y = 14.1x - 7.87	r^2 = 0.31	y = 31.5x - 38	r^2 = 0.63	y = 4.72x + 11	r^2 = 0.40
		9	y = 10.3x - 4.64	r^2 = 0.31	y = 20.4x - 26	r^2 = 0.55	y = 16.4x - 7.01	r^2 = 0.54
		11	y = 12.7x - 18	r^2 = 0.39	y = 21.3x - 34	r^2 = 0.50	y = 16.9x - 12	r^2 = 0.48
	$NDVI_{red}$	6	y = 153x - 70	r^2 = 0.28	y = 326x - 166	r^2 = 0.52	y = 208x - 81	r^2 = 0.45
		9	y = 178x - 101	r^2 = 0.26	y = 336x - 203	r^2 = 0.41	y = 270x - 149	r^2 = 0.40
		11	y = 212x - 134	r^2 = 0.24	y = 390x - 256	r^2 = 0.38	y = 276x - 161	r^2 = 0.29
	$NDVI_{red-edge}$	6	y = 128x - 27	r^2 = 0.29	y = 277x - 76	r^2 = 0.56	y = 174x - 22	r^2 = 0.48
		9	y = 151x - 52	r^2 = 0.31	y = 280x - 107	r^2 = 0.48	y = 228x - 74	r^2 = 0.48
		11	y = 181x - 74	r^2 = 0.33	y = 311x - 131	r^2 = 0.44	y = 240x - 85	r^2 = 0.40

Table 4.8. The relationship of SR and NDVI measured at 6 to 14 WAN application with cellulose and hemicellulose of energy cane stalk harvested at different dates and year.

Year/Crop	Vegetation Indices (VIs)	Weeks after N (WAN) application	Two-Months Earlier Harvesting	One-Month Earlier Harvesting	Scheduled Harvest
2013, Plant Cane	SR_{red}	6	y = 67.2x + 684 r^2 = 0.24	y = -0.68x + 1203 r^2 = 3E-05	y = -13.4x + 1546 r^2 = 0.01
	$SR_{red-edge}$	6	y = 227x + 402 r^2 = 0.28	y = 20.8x + 1125 r^2 = 0.003	y = -12.5x + 1487 r^2 = 0.001
	$NDVI_{red}$	6	y = 2311x - 532 r^2 = 0.22	y =-24.6x + 1216 r^2 =3E-05	y = -348x + 1704 r^2 = 0.005
	$NDVI_{red-edge}$	6	y = 2097x + 62 r^2 = 0.24	y = 254x + 1060 r^2 = 0.004	y = -46.9x + 1469 r^2 = 0.0001
2014, First Ratoon	SR_{red}	6	y = 43.1x + 683 r^2 = 0.16	y = 26.2x + 1076 r^2 = 0.06	y = 51.9x + 8775 r^2 = 0.27
		8	y = 27.1x + 667 r^2 = 0.18	y = 23.4x + 981 r^2 = 0.13	y = 29.2x + 905 r^2 =0.24
		14	y = 79.8x + 1.02 r^2 = 0.28	y = 59.1x + 533 r^2 = 0.15	y = 98.6x + 24 r^2 = 0.49
	$SR_{red-edge}$	6	y = 127x + 555 r^2 = 0.18	y = 82.1x + 979 r^2 = 0.08	y = 141x + 766 r^2 = 0.25
		8	y = 83.2x + 594 r^2 = 0.16	y = 64.9x + 950 r^2 = 0.10	y = 89.4x + 826 r^2 = 0.22
		14	y = 214x + 19 r^2 = 0.28	y = 168x + 501 r^2 = 0.17	y = 249x + 113 r^2 = 0.44
	$NDVI_{red}$	6	y = 1670x - 228 r^2 = 0.19	y = 1175x + 402 r^2 = 0.10	y = 1886x - 126 r^2 = 0.28
		8	y = 1117x + 95 r^2 = 0.06	y = 1376x + 134 r^2 = 0.11	y = 1194x + 296 r^2 = 0.08
		14	y = 6982x - 4923 r^2 = 0.24	y = 5692x - 3561 r^2 = 0.17	y = 9123x - 6484 r^2 = 0.47
	$NDVI^{red-edge}$	6	y = 1398x + 250 r^2 = 0.20	y = 979x + 742 r^2 = 0.11	y = 1498x + 460 r^2 = 0.26
		8	y = 1205x + 237 r^2 = 0.11	y = 1146x + 533 r^2 = 0.11	y = 1278x + 454 r^2 = 0.15
		14	y = 3568x - 1270 r^2 = 0.28	y = 2939x - 601 r^2 = 0.19	y = 4175x - 1397 r^2 = 0.45
2015, Second Ratoon	SR_{red}	6	y = 30.9x + 528 r^2 = 0.11	y = 124x + 365 r^2 = 0.62	y = 94.2x + 809 r^2 = 0.58
		9	y = 18.1x + 579 r^2 = 0.10	y = 65.9x + 548 r^2= 0.44	y = 58.6x + 853 r^2 = 0.48
		11	y = 23.6x + 478 r^2 = 0.16	y = 70.3x + 385 r^2 = 0.50	y = 59.9x + 743 r^2 = 0.51
	$SR_{red-edge}$	6	y = 76.8x + 484 r^2 = 0.10	y = 324x + 125 r^2 = 0.64	y = 245x + 633 r^2 = 0.58
		9	y = 56.8x + 510 r^2 = 0.10	y = 202x + 321 r^2 = 0.46	y = 185x + 622 r^2 = 0.54
		11	y = 78.8x + 389 r^2 = 0.16	y = 230x + 144 r^2 = 0.50	y = 209x + 470 r^2 = 0.58
	$NDVI_{red}$	6	y = 878x + 109 r^2= 0.10	y = 3461x - 1274 r^2 = 0.57	y = 2775x - 544 r^2 = 0.58
		9	y = 1091x - 110 r^2 = 0.10	y = 3625x - 1674 r^2 = 0.41	y = 3274x - 1165 r^2 = 0.46
		11	y = 1179x - 210 r^2 = 0.08	y = 4349x - 2370 r^2 = 0.40	y = 3615x - 1529 r^2 = 0.38
	$NDVI_{red-edge}$	6	y = 684 + 388 r^2 = 0.09	y = 2912x - 294 r^2 = 0.60	y = 2265x + 281 r^2 = 0.57
		9	y = 858x + 235 r^2 = 0.11	y = 2925x - 576 r^2 = 0.44	y = 2706x - 214 r^2 = 0.52
		11	y = 1021x + 117 r^2 = 0.11	y = 3420x - 938 r^2 = 0.46	y = 3047x - 472 r^2 = 0.50

Table 4.9. Range of coefficient of determination of vegetation indices measured from 6 to 14 WAN application with millable stalk and fiber yield of cane harvested at different dates, 2013-2015, St. Gabriel, LA.

Weeks after N (WAN) application	Purpose	Coefficient of Determination (r^2)		
		Two-Months Earlier	One-Month Earlier	Scheduled Harvest
6 – 9	Nitrogen Management[+]	0.10 – 0.35	0.17 – 0.60	0.34 – 0.59
11 – 14	Stalk Yield Estimation	0.10 – 0.31	0.30 – 0.42	0.41 – 0.60
6 – 14	Cellulose and Hemicellulose Yield Estimation	0.10 – 0.28	0.003 – 0.63	0.01 – 0.58

[+] Limited used based on current timeline of N application in Louisiana sugarcane production systems.

4.4 Conclusions

Optical sensor-based prediction of millable stalk, N uptake, and fiber yield has profound role on timely implementation of effective management of N fertilizer and handling of feedstock during harvesting due to its accuracy and speed. This study demonstrated the use of SR and NDVI computed from reflectance readings at wavebands 670 nm (red) and 705 nm (red-edge) for a better estimation of stalk yield, N uptake, and fiber yield across cane age. Furthermore, the computed VIs can estimate stalk yield, N uptake, and fiber yield better for cane when harvested at scheduled date. Perhaps this indicates that the applicability and accuracy of fiber yield estimation largely relies on cane maturity.

Thus far, this study demonstrated the feasibility using VIs collected between 6 and 9 WAN application (approximately June to mid-July) as estimates of stalk yield. Although this period was considered outside the current timeframe of N application, it might be useful in the future for N fertilizer management in Louisiana energy cane production system. The VIs collected at 11 to 14 WAN (approximately mid-July to August) can be used for yield estimation that can provide information for a more efficient handling of feedstock. For fiber yield estimation, the possibility seems limited for ratoon crops but can be done for VIs collected as early as 6 WAN application. This study revealed several limitations and strengths of optical sensing technology as tool for yield prediction in energy cane production which can provide insights on several factors (e.g. optimal sensing date, SR vs. NDVI, red vs. red-edge) so that future research can focus on areas in optical sensing technology that will ensure success to yield useful outcomes. For future research which will be designed to develop a generalized yield prediction model, building a large database combined with data transformations (e.g. incorporation of GDD, adjusting NDVI based on crop age) are essential.

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Chapter 5. Conclusions

The existing sugarcane industry in Louisiana is perceived as an advantage for biofuel industry because of the similarities of energy cane and sugarcane by way they are cultivated, harvested, and processed. Dedicated energy crops for second generation bioenergy production should be high yielding, fast growing, have low lignin content, and require relatively lower inputs for its growth and harvest. The level and quality of dry matter produced by cane was not affected by planting method. On average years, billet planting has more advantages over whole stalk planting and therefore billets can be a logical choice as planting material in energy cane production. In addition, the absence of differences in nutrient removal rate between whole stalk- and billet- planted cane suggests that the fertilizer recommendation will remain virtually the same for these two planting scheme. Considering the ease in planting and harvesting particularly under the condition of severe cane lodging and lack of labor availability, billet planting appears to be an option for the Louisiana energy cane production. More likely in the end, the availability of farm machineries and equipment, seeds, and labor will be the determining factors for adoption of planting method. This study clearly demonstrated that energy cane yield (stalk and leaves), quality parameters (TRS, brix, sucrose, and fiber), chemical composition (hemicellulose, cellulose, and lignin), and nutrient concentration and uptake were significantly affected by harvest date. The lignocellulosic component and nutrient concentration and uptake did not show consistent trend in response to harvest date. Another notable outcome from this study was that the application of N did not offer any advantage in terms of yields, sugar quality parameters, lignocellulosic component, and acquisition of plant-essential nutrients from the soil over the unfertilized-N plots for the three successive cropping years. Energy cane appears to be more efficient in the utilization of applied nutrients thus eliminating large application of nutrients particularly N which is considered a big investment in cane production. Therefore, it is more economical, sustainable, and environmental friendly due to reduction of risk arising from excessive application of N. This study showed also the potential use of residue (leaves) as an additional source of feedstock for energy production. However, the value of residues in terms of CO2 sequestration and nutrient cycling if left on the field versus harvesting for additional feedstock should be weighed out carefully. The long-term effect of continuous farming coupled with complete removal of leaf biomass from the field potentially includes decline in soil quality and productivity.

The outcomes of this study provide insights on the areas of research to focus when considering earlier harvest dates and residue collection (whole plant harvesting) in energy cane production. These include the role of ripeners application on energy cane yield, fiber composition, and nutrient removal rate, and documentation on the long-term impact of whole plant harvesting on soil quality and productivity.

Furthermore, optical sensor-based prediction of millable stalk, N uptake, and fiber yield has profound role on timely implementation of effective management of N fertilizer and handling of feedstock during harvesting due to its accuracy and speed. This study demonstrated the use of SR and NDVI computed from reflectance readings at wavebands 670 nm (red) and 705 nm (red-edge) for a better estimation of stalk yield, N uptake, and fiber yield across cane age. Thus far, this study demonstrated the feasibility using VIs collected between 6 and 9 WAN application (approximately June to mid-July) as estimates of stalk yield. Although this period was considered outside the current timeframe of N application, it might be useful in the future for N fertilizer management in Louisiana energy cane production system. The VIs collected at 11 to 14 WAN (approximately mid-July to August) can be used for yield estimation that can provide information for a more efficient handling of feedstock. For fiber yield estimation, the possibility seems limited for ratoon crops but can be done for VIs collected as early as 6 WAN application. This study revealed several limitations and strengths of optical sensing technology as tool for yield prediction in energy cane production which can provide insights on several factors (e.g. optimal sensing date, SR vs. NDVI, red vs. red-edge) so that future research can focus on areas in optical sensing technology that will ensure success to yield useful outcomes. For future research which will be designed to develop a generalized yield prediction model, building a large database combined with data transformations (e.g. incorporation of GDD, adjusting NDVI based on crop age) are essential.

Vita

Marilyn Sebial Dalen was born in September 11, 1979, in Leyte, Philippines. She finished her Bachelor of Science degree in Agriculture major in Soil Science in 2000 at the Visayas State University, Philippines. Upon completion, she worked in the same university as a science research assistant on several projects funded by international institutions from 2000 to 2010. In January of 2011 she was admitted into the Master of Science degree program in the School of Plant, Environmental, and Soil Science at Louisiana State University Agricultural and Mechanical College. She is under the guidance of Dr. Brenda Tubana working on phosphorus nutrition on corn grown on alluvial soils of Louisiana. The title of her thesis is “Understanding phosphorus dynamics of two alluvial soils grown with corn at different phosphorus rates”. She completed her MS degree program on December 2012 and continued her doctoral degree program in the School of Plant, Environmental, and Soil Science at Louisiana State University Agricultural and Mechanical College still under the guidance of Dr. Tubana. Her Ph.D. research project revolves around the application of optical sensing technology in managing nitrogen fertilizer and yield prediction in energy cane production in Louisiana. The title of her dissertation is “Integration of Optical Remote Sensor-Based Yield Prediction and Impact of Nitrogen Fertilization, Harvest Date, and Planting Scheme on Yield, Quality, and Biomass Chemical Composition in Energy Cane Production in Louisiana”.