Evaluating the use of renewable fuel sources to heat flue-cured tobacco barns

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ABSTRACT

The curing of flue-cured tobacco (*Nicotiana tabacum* L.) is an energy intensive process and represents a significant portion of the overall cost of production. Given the goal of the industry to reduce the environmental footprint of tobacco production and the energy demand of curing, attention has been directed to explore options for the use of renewable fuels for heating tobacco barns. A two-year study conducted at the Virginia Tech Southern Piedmont Center evaluated the effectiveness and cost of curing flue-cured tobacco with a wood pellet burner. Additionally, field studies were conducted to evaluate the feasibility of on-farm production of biomass fuel crops as well as on-farm manufacture of biomass fuel pellets. The first time use of a wood pellet burner with an air-to-air heat exchanger in a bulk curing barn proved to be a viable alternative to a conventional propane fueled burner. Curing cost averaged $0.05 with the pellet burner compared to $0.04 per kilogram of tobacco with the propane burner. The increase in cost was offset by a 90 percent reduction of CO_2 emissions with the use of wood pellets. The use of low lignin grass varieties did have an impact on biomass pellet properties. Pellet testing revealed high ash and chloride levels which could be problematic using a high efficiency wood pellet burner. Full maturity harvest of annual grasses fertilized with 112 kg per ha N resulted in higher yields. However, fertilizing for maximum yield would increase the CO_2 footprint for biomass fuel pellet production.

Abstract

Curing flue-cured tobacco (*Nicotiana tabacum* L.) is an energy intensive process consuming large quantities of both propane and electricity and represents the second highest overall production cost. The tobacco as a whole has a goal to reduce the environmental footprint of tobacco production and the energy demand of curing. In order to produce the crop more sustainably, attention has been directed to explore options for the use of renewable fuels for heating tobacco barns. Currently utilizing renewable fuels is limited to a small number of wood-fired hot water boiler systems. A two-year study conducted at the Virginia Tech Southern Piedmont Center evaluated the effectiveness and cost of curing flue-cured tobacco with a wood pellet burner. Additionally, field studies were conducted to evaluate the feasibility of on-farm production of biomass fuel crops as well as on-farm manufacture of biomass fuel pellets. The first time use of a wood pellet burner with an air-to-air heat exchanger in a bulk curing barn proved to be a viable alternative to a conventional propane fueled burner. The wood pellet burner with air-to-air heat exchanger was compared to a high efficiency prototype propane burner. Curing cost averaged \$0.05 with the pellet burner compared to \$0.04 per kilogram of tobacco with the propane burner. The increase in cost was offset by a 90 percent reduction of CO_2 emissions with the use of wood pellets. Curing cost with the wood pellet burner is expected to be lower than that of a more traditional propane burner and curing barn. The use of low lignin grass varieties did have an impact on biomass pellet properties, however more replications testing on-farm produced pellets is necessary in order strengthen the validity of these results. Pellet testing revealed high ash and chloride levels in on-farm produced biomass pellets which could be problematic using a high efficiency wood pellet burner, but may be less precarious if paired with a more rudimentary burner. Full maturity harvest of summer annual grasses

fertilized with 112 kg per ha N resulted in higher yields. However, fertilizing for maximum yield would increase the CO_2 footprint for biomass fuel pellet production. Based on these results, purchasing commercially made, readily available wood pellets is the best alternative to using a renewable fuel to cure flue-cured tobacco. This practice would allow growers to incrementally adopt the use of a renewable fuel while providing comparable operation ease as traditional propane burners.

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Chapter I

Introduction

Virginia has historically produced five different types of tobacco which are flue-cured, burley, fire-cured, dark air-cured and sun-cured. Flue-cured tobacco is grown in southern Virginia. Burley tobacco is an air-cured tobacco grown primarily in the southwest portion of the state. Dark fire-cured tobacco is grown in a few counties in the central piedmont while sun-cured is a dark tobacco that is air-cured. Production of both dark tobacco types is limited. Flue-cured tobacco represents approximately 90 percent of Virginia's tobacco production. The tobacco is named for the unique curing method where heat provided through the means of a metal flue pipe is used to cure the tobacco but limits the exposer to smoke and other products of combustion (Collins and Hawks 1993). Historically, barns were heated with wood fires and the heat entered the barn through flue pipes. In the early to mid-20th century, wood was replaced by fuel oil and then later, fuel oil was replaced by propane and natural gas. Present bulk tobacco curing barns consume considerable amounts of fuel for heating and electricity for forced air ventilation. Given the fact that tobacco is not a food crop and significant energy is associated with tobacco production, the industry has focused resources to reduce the overall energy usage with efforts to lower the environmental footprint of tobacco production (Altria 2017).

Flue-cured bulk tobacco barns are specially constructed barns that have forced air ventilation and supplemental heat. In Virginia this heat is fueled almost exclusively by propane. The curing cycle is a specialized drying process where temperature and the rate of moisture removal are regulated to produce specific color and chemical changes in the leaves (Sykes 2008). During this process 85% of the original weight is removed as water. This process is highly energy intensive in both fuel and electricity consumption and is continuously being improved to achieve greater and greater efficiencies. Curing cycles generally last from 6 to 7 days and result in 3000 to 4000 pounds of cured tobacco per barn. Each bulk curing barn on farms is used approximately 6 to 10 times per season. Figure 1.1 displays a graph of a typical flue-cured tobacco curing schedule. The red line represents the temperature inside the barn while the blue line corresponds with the wet bulb temperature which is used to determine relative humidity. Relative humidity is depicted by the green dotted line. The temperatures incrementally increase throughout the curing cycle until the tobacco is completely dried. Likewise the relative humidity incrementally decreases throughout the curing cycle (Boyette and Ellington 2005).

Tobacco curing cycles consume large amounts of energy and are also responsible for considerable amounts of greenhouse gas pollution being emitted into the atmosphere. Generally curing tobacco with propane requires 0.10 to 0.12 gallons of propane to produce 1 pound of cured tobacco. This equates to around 300-480 gallons of propane being consumed during each curing cycle. The combustion of propane emits 12.7 pounds of CO_2 per gallon burned (U.S. Energy Information Administration 2016), which equates to a single curing cycle emitting 3810-6096 pounds of CO_2 when propane is used as the fuel source. In 2016, approximately 5M and 35M gallons of propane were used in Virginia and the overall flue-cured region in the U.S., respectively. Corresponding CO_2 emissions were 63.5M and 444.5 M lbs. CO_2. The environmental footprint of tobacco production, specifically the curing process, is a major focus of the tobacco industry. The use of renewable energy is frequently discussed as a means of lowering the industry's carbon footprint.

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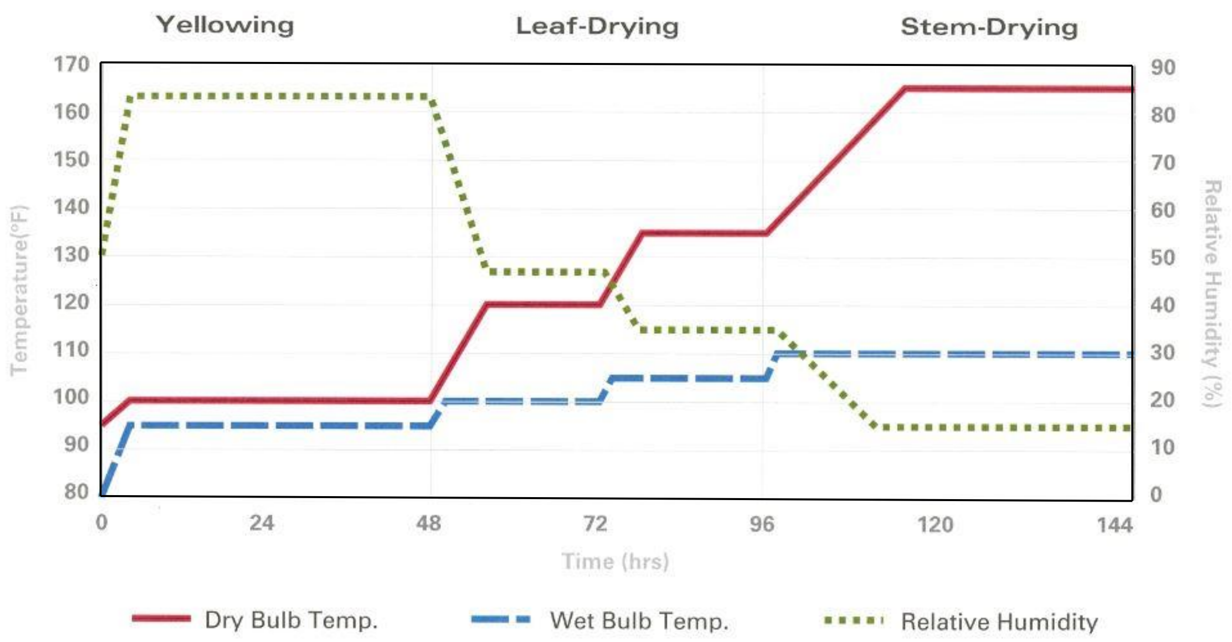

Figure 1.1. A typical curing schedule for flue-cured tobacco. The dry bulb temperature is the air temperature in the barn and the wet bulb temperature is related to the moisture in the tobacco and the barn.

Chapter II

Literature Review

Reasoning for renewable energies

Renewable energy sources and their economic benefits are attracting national as well as global attention in recent years (Lester et al. 2015). Energy derived from biomass is projected to contribute 50 percent of the energy needed by developing countries by the year 2050 (Demirbras, 2008). Prior to the 20th century the United States relied heavily on wood and other biomass as its major fuel source. However, with dwindling supplies and the introduction of convenient high energy fossil fuels to the market, the use of biomass as a fuel source decreased until recent years (Maungl et al. 2013). The reintroduction of biomass as a fuel source is largely contributed to a society that is more focused on environmental conservation and preventing climate change. This is accomplished by slowing the degradation being done to the environment and repairing previous environmental deterioration.

This change in societal opinion of renewable fuels is shown through the increasing numbers of states in America that have adopted renewable portfolio standards (RPS). Renewable portfolio standards are voluntary goals set in place to mandate that a certain portion of a state's utility energy needs are met with energy generated from renewable energy sources (Lester et al. 2015). Currently there are twenty nine states that have adopted these RPSs, which excludes Virginia (Dincer et al. 2014).

Biofuels are one of the more prominent renewable energy sources that are being implemented in these RPS's. Biofuels include liquid, gas and solid fuels predominantly produced from biomass. More specifically, ethanol, bio-diesel and densified biomass in the form of pellets or larger briquettes are commonly known and utilized forms of biofuels. In order to mitigate global climate change caused by greenhouse gas emissions the developed world has to start replacing fossil fuel usage with renewable fuels such as biofuels (Parikka, 2004). Many developed countries have an economy that is very dependent on fossil fuel usage as their primary fuel source. Particularly in the U.S., a loss of fossil fuel supply as well as an ever increasing demand for imported crude oil has led to a major increase in expanding the bio-energy industry (Demirbras, 2008). Maungl et al. (2013) stated that recent increases in oil prices, concerns for climate change and lack of stability in the Middle East have led to a rise in interest of biofuels. For these reasons, the U.S. government has committed to increase the biofuel energy industry in the USA by three fold within ten years. In addition to regulatory or legislative mandates there are potential societal benefits to the use of biofuels. Puppan (2002) described traits of biofuels as: Biofuels are available from many common biomass sources including many agricultural products, biofuels represents a closed carbon dioxide cycle in combustion, they have large environmental potential, additional consumer and economic benefits and finally biofuels contribute to sustainability and are biodegradable.

<u>Biomass as a fuel source</u>

The term biomass covers a broad range of materials. Popp (2013) defines different categories of biomass and states the term biomass covers vegetation on land and in water as well as organic wastes Biomass is also subdivided into primary, secondary, or tertiary. ”Primary biomass feedstocks are materials harvested or collected directly from forest or agricultural land where they are grown (e.g., grains). Secondary biomass feedstocks are by-products of the processing of primary feedstocks (e.g., maize stover, sawmill residues, black liquor). Tertiary biomass feedstocks are post-consumer residues and waste (e.g., waste greases, wastewaters, municipal solid waste).” In the broad spectrum of the global economy, solid fuels, especially biomass fuels are beginning to gradually replace natural gas as a fuel source (Mani et al. 2006a). Improved technology in fossil fuel discovery and utilization does not always provide long term solutions to a consistent energy supply. Such is true with the Marcellus Shale deposit. The economic viability of Marcellus Shale deposit in the U. S. is not viable according to Duman (2012). Increased production cost, overproduction issues, and a deteriorating natural gas market has led to economic issues associated with hydraulic fracturing for natural gas production.

Crops for biofuel

Interest for the greater usage of biofuels in the United States increased in the mid to late-2000's. However, ethanol production from a cellulosic feedstock, such as grains, has been commercially used since the First World War (Hasting et al. 2013). Early in the search for an alternative renewable fuel source ethanol produced from grain crops was highly sought after and researched. The International Energy Agency (IEA) projects that biofuels can increase from the current 2% to around 27% of all liquid transportation fuels by 2050 (Jaradat, 2013). Achieving the increase in biofuel used for transportation can only be reached sustainably if the proper technologies are utilized and the correct diplomatic policies are set in place. The use of food crops to produce ethanol for fuel source has one major drawback which is these grains are used to feed people and livestock around the globe. Many individuals and interest groups dislike the concept behind converting a food product into a fuel source. The increased use of biofuel liquids produced from grain led to an increase in food prices which in turn negatively impacted the enthusiasm behind using grain produced biofuels as a mean to lower global greenhouse gas emissions (Jaradat, 2013).

In recent years there has been strong development in research towards a biofuel that is not converted into liquid but is kept in solid form and burnt for energy. Fike et al. (2013)

compiled a list of 13 biological, environmental and agronomic factors that can be used to determine the potential of a crop to be a sustainable biomass fuel source. The 13 traits, characteristics or factors include: ease of establishment, adaptation to target site, geographic/stress range, pest susceptibility, weediness, biomass yield, feedstock quality, seed/propagule production, breeding potential, grower acceptance or perception, input requirements, management requirements and other environmental impacts. A potential biomass crop species would need to rank high in most, if not all, of these 13 categories in order for it to be considered a sustainable fuel alternative. Fike et al. (2013) discusses the benefits of implementing perennial crops in view of the fact that perennial stands would persist year after year with the establishment wait time being a single occurrence. Along with contributing to the reduction of anthropogenic carbon dioxide, Fournel *et al.* (2015) states that other environmental benefits will be shown. Such benefits would include: soil erosion prevention, limited soil management such as nutrient inputs, and restoration of degraded, marginal or abandoned lands.

There are many possible perennial genera that have potential to be productive viable biomass fuel crops. Fike *et al.* (2013) compiled a list of plant geniuses that would be most suitable for growing as a biomass crop based on a database search**.** The top 3 genera based on occurrences were *Saccharum*, *Panicum* and *Sorghum*. The *Saccharum* genus consists of high sugar content plants with stout fibrous stalks that grow to a height of 1.8-5.8 m. Sugarcane species are a common species in this genus. *Panicum* is a large genus that covers about 450 species of perennial and annual grasses that grow from 0.9-2.7 m. tall. Switchgrass and millet species fall under this genus. *Sorghum* is a genus of flowering grasses that reach a growing height of 1.8-3.7 m. Different species in the sorghum genus are cultivated for grain or for forage and includes Johnson grass (*S. halapense*) which is often considered a nuisance and invasive species in the Mid-Atlantic region of the United States.

Many crops can be used to produce bioenergy, however El Bassam (2010) summarized a list of criteria that if met by a crop then it can be categorized as a bioenergy crop. The first criterion is whether the plant is being grown for starch or sugar to produce ethanol. Secondly, if a plant is being grown specifically for oil as a feedstock of biodiesel it is a bioenergy crop. Thirdly, a crop can be associated with bioenergy crops if production is used as solid biomass to obtain electricity and heat either through direct combustion or indirectly through fuel conversion. Lastly, any crop that is cultivated for the production of biogas is considered a bioenergy crop.

Perennial biomass fuel crops will play a major role in the creation of a reliable and sustainable non-food fuel source. With the increasing demand for livestock feed that is currently projected to increase with the food demand by 40% in 2030 and up to 70% by 2050 (Popp, 2013) the necessity to have a renewable biomass fuel source that does not interfere with food production will also increase. Producing renewable biomass as a fuel stock, in order to be sustainable, will need to not interfere with food production or the lands where they are grown. The projected 30% increase in global population to nearly 9.2 billion by 2050 Popp (2013) will require more high quality food than ever needed before. As the population of developing countries increases the desire to improve their quality of life will also increase. Diets will evolve to include more meat and dairy products thus decreasing potential biomass stock suitable for fuel due to the increased need of feed for livestock producing meat and dairy products.

<u>Wood byproducts</u>

Waste wood products are valuable as fuel sources. In general wood waste products consist of bark, course residues such as slabs and edgings, cores, sawdust, planer shavings, sander dust and particleboard waste (Parikka, 2004). Waste wood byproducts can be used as a fuel source directly without further processing or be converted into densified biomass. Waste wood products can be burned as an almost carbon neutral energy source and with proper infrastructure waste wood products can be used in most situations as a fuel source. Wood byproducts that can be used as a fuel source are underutilized in developed countries (only 25%) compared to developing countries (75%) (Parikka, 2004). North America has the potential to greatly increase the proportion of energy needs being met with renewable fuel sources like biofuels, especially those derived from wood by products. Approximately 25% of the North American continent is forested area causing North America to have the potential to provide very considerable amounts of energy (19.9 EJ/a) but currently only 16% is utilized (Parikka, 2004). The small utilization of wood and wood byproducts in North America is associated with inexpensive and readily available fossil fuels as well as an infrastructure system based around fossil fuels. Overall biomass production for energy purposes has potential to pollute water resources, decrease food security, and threaten conservation areas (Field, et al. 2007)

Agriculture waste products

The increase in production of staple agricultural commodities has led to a large supply of agricultural waste products. Cotton, peanuts, cherries, vegetables, and many more agricultural products produce significant amounts of waste. These by-products and waste residues contain large quantities or lignocellulosic materials (Dietrich et al., 2016) and can be used as a fuel source much like forest pulp products. Fruit and vegetable waste has the potential to provide large amounts of feedstock as biofuel due to 45% of total fruit and vegetable biomass being wasted during some stage in the supply chain. This large percentage is being disposed in landfills and waterways causing environmental damage (Dietrich et al., 2016). The potential to create a viable biofuel from agricultural waste products has a promising future, but there are some negative attributes associated with converting agricultural waste products into biofuels. One major problem is the seasonality of the waste feedstock. During harvest or processing season there will be a surplus of the needed feedstock, alternatively, during the off season there is a shortage. This leads to the need of storage facilities and more complications with preserving the feedstock. Some agricultural waste, such as fruit and vegetable waste, has high a moisture content which is a storage problem due to microbial breakdown (rotting) occurring (Dietrich et al., 2016). For this reason, high moisture waste has to be either dried before storage or processed immediately. A second concern is low bulk density of agriculture waste prior to processing, especially if the final outcome is pelletized fuel. Such waste feedstocks require large spaces to be store and increased moisture paired with low bulk is logistically problematic.

Environmental impacts

The primary factor attributed to climate change is the production of greenhouse gases being emitted into the atmosphere. Carbon dioxide (CO_2), methane (CH_4), water vapor, and nitrous oxide (N_2O) are the main greenhouse gases (Singh, 2013). The current dependence on fossil fuels as the main energy source for industrial and residential use is resulting in increased greenhouse gas emissions. The use of biomass as a renewable energy source has great potential to reduce these emissions and the advance of climate change (Fournel et al., 2015).

The European Union has recognized the potential of biomass fuels to reduce greenhouse gas emissions up to 60% by 2018 (Soimakallio and Koponen, 2011). Cellulosic biomass accumulates carbon dioxide from the atmosphere to be stored internally. Biomass that naturally occurs is considered, in theory, carbon neutral because when the plant dies and is either burned as a fuel or decomposes in the environment that plant releases its stored carbon dioxide back into the atmosphere. According to these two principals utilizing biomass as a fuel source is carbon neutral (Singh, 2013). However, this is not considered to be the case when crops are planted for the intended purpose of being a biofuel. Inputs associated with producing these crops such as fertilizers, fossil fuel usage (gasoline and diesel fuel) and transportation cost all factor into the carbon footprint. Fournel et al. (2015) stated that biomass from energy crops can prevent soil erosion while requiring limited management and inputs showing that biomass produced as a fuel source, even with the necessary inputs, can reduce greenhouse gas emissions. Tillage for seed bed preparation increases the potential for erosion, however, installment of perennial crops would limit tillage to a one time occurrence. No-till technologies are also a method to plant biomass energy crops with limited erosion risk.

Pellet standards and explanations

Biofuel pellets are an alternative heating fuel source that has many applications. Densification (pelletizing), measured by bulk density, is essential in utilizing biomass as a fuel source due to the great efficiency improvements in transport, handling and storage logistics (Jackson et al. 2016). Once the proper handling and burning infrastructure is installed, fuel pellets can be used in the same situations as propane or natural gas. Fuel pellets created from biomass have standards used for measuring pellet quality that are imperative when utilizing fuel pellets. The Pellet Fuels Institute (PFI) is an accredited third party program that ensures consumers receive quality fuel pellets. The PFI has created a set of standards that pellets must meet in order to obtain their premium inspection seal (Pellet Fuel Institute). These standards represent important qualities of biofuel pellets that impact their potential as a fuel such as bulk density, pellet diameter, percent fines, percent ash content, length, moisture content and chlorides.

Benefits of Pellets

The global economy is highly dependent on the use of fossil fuels for the energy needs of industrial production, transportation and food production. Of the actual energy demand for the world, 86 percent is fulfilled by fossil fuels (Poddar et al., 2014). Densified biomass pellets offer an alternative energy source that often has benefits to the environment and economy. There are three main reasons that biomass is a suitable feedstock for pelleting. First, biomass is a feedstock that is a renewable resource and has great potential to be developed in the future. Second, biomass has positive environmental properties due to the limited release of carbon dioxide. Third, biomass appears to have significant economic potential as long as the price of fossil fuel increases in the future (Demirbras, 2008). Pelletizing biomass increases density which improves logistics and homogeneity as well as contributing to a more uniform combustion process (Fournel et al., 2015).

The constant growing concern for greenhouse gas emission creates a much stronger demand for a lower carbon or carbon neutral energy source. Production of pellets has rapidly grown in recent years in Europe, China and northeast America (Gil et al., 2010). With this as a major driving force, biomass pellets have become a large industry due to the fact that biomass pellets produce minimal carbon pollution (Sultana et al., 2010) due to the CO_2 that is emitted during combustion is reabsorbed by the plant as it regrows. These pellets can be produced from a variety of agriculture and forestry waste products such as cotton, peanut, grape and coffee waste as well as hard and softwood sawdust and chips (Gil et al., 2010).

Pellet production in different mill types

In some cases pellet mills that once produced animal feed were repurposed to produce wood pellets. However, these mills were not designed to handle wood and the applicability was limited to mainly small scale personal use (Obernberger and Thek, 2010). Research and development has led to producing densified biomass fuel pellets on a large scale. Pellet mills operate at a massive industrial production scale of greater than 150,000 Mg per year down to a homeowner scale with capabilities of producing 45 kg per hour. Sultana et al., (2010) found a decrease in production cost of pellets with an increase of production. However, they also found there is a threshold around 70,000 Mg per year and once that output is crossed the cost of pellet production remains fairly similar.

The process of densifying biomass into pellets is accomplished either by a flat die or a ring die style of pellet mill. Large scale production normally occurs by using ring die pellet mills specifically designed for wood. This type of mill consists of a die ring that rotates around fixed rollers. The feedstock is fed in horizontally where it is pressed through the die holes from the inside out. On flat die pellet mills the fixed rollers sit atop of the flat, horizontal orientated die. While the die is rotating the material is fed in vertically from above and pressed downward through the die holes (Obernberger and Thek, 2010).

Economics

Producing biomass fuel pellets economically is viable. The growing pellet market in the United States is becoming a major industry, especially in the northeast. The viability of producing biomass fuel pellets depends on the size of the production plant and the availability and cost of the raw feedstock. Mani et al. (2006a) found the production cost of pellets is inversely affected by the rate at which a plant can produce pellets. As the hourly production rate of the pellet mill increases the total cost per ton decreases (Mani et al., 2006a). The plant's capacity for production is a critical issue when determining whether the pellets will be economical compared to other fuel sources.

Moisture effects on pelleting

Feedstock moisture is the area of most concern when pelleting biomass. Moisture in raw material that is being prepared to pelletize acts as a binder which leads to moisture levels effecting pellet density and diametric compression strength. Both of these parameters influence the grade standard allowed to be placed on pellets. In many cases, a difference in these characteristics will cause poor efficiency in end use pellet burner. Zhang et al. (2015) found in a study producing densified water hyacinth pellets that moisture content has effects on density and diametric compression strength. They tested 5 different moisture levels (8, 10, 12, 14, 16 percent moisture) and found that 12.2% and 11.5% moisture produced the highest pellet density and diametric compression strength respectively.

Pelleting temperature on quality

Pelletizing raw biomass in mills requires heat. Heat is needed to break down particles of biomass and permanently bond the biomass to form pellets. Pelleting biomass material at an overly high temperature can lead to charring of the material which has unfavorable densification properties. Zhang et al. (2015) found that the highest pellet density and diametric compression strength were achieved by pelletizing material at 100.4 ^{0}C and 104.3 ^{0}C respectively. Biomass material is preheated with dry steam in commercial pelleting facilities before entering the pellet mill. In consumer grade flat die pellet mills the necessary heat is created by friction between the pellet die and rollers (Obernberger and Thek, 2010).

On farm storage of pellets

Densified biomass fuel pellets can be stored safely and cheaply in a homogenous manner as small grains (Mani et al., 2006a). Fuel pellets can be stored in large grain bins, mini bulk bags and 40 lb plastic bags packed on pallets. Pellets can be handled much like corn. They can be fed through traditional grain augers to move from trucks into storage bins. The moisture content of pellets is approximately 8 percent, and have a high bulk density of around 600 kg per m^3 or higher. These two properties allow for safe and efficient storage and transport (Mani et al., 2006b). This could either come in mini bulk bags, or loose in road tractor grain trailers. Safely storing and handling pellets is no more difficult than handling gaseous or liquid fuels once the proper facilities and handling equipment is in place.

Lignin effect on pellets

Lignin is a generic term referring to a large group of aromatic polymers that resulted from the oxidative combinatorial coupling of 4-hydroxyphenylpropanoids (Boerjan et al., 2003; Ralph et al., 2004). Lignin polymers are predominantly deposited in secondarily thickened cells causing these cells to become ridged and impervious (Vanholme et al., 2010). The lignin content of a biomass material has an impact on pellet quality outcome. Lignin impacts both the physical properties (pellet durability, fines) as well as the chemical properties (caloric combustion value) of biomass pellets (Demirbras, 2001). The presence of lignin in biomass feedstock greatly improves the binding characteristics of the compressed pellets when the material is heated. This is caused by lignin becoming soft and sometimes melting and exhibiting thermosetting properties (Mani et al., 2006b). Lignin in the raw biomass material acts as naturally occurring glue, binding the produced pellets (Mani et al., 2006a). When additional binding agents are not needed, the production cost associated with purchasing and incorporating binders into the pellets is reduced or does not exist and lowers the overall cost of pellets. Lignin contributes to higher heat of combustion (Podder et al., 2014) and Demirbas (2001) also found that the lignin content in biomass has a direct linear correlation with the higher heating value (HHV) of biomass. Increased amounts of lignin available in plant biomass equates to increased HHVs (Demirbas, 2001). Knowing which types of biomass contain high amounts of lignin is beneficial due to the benefits in pellet durability and heating values associated with biomass containing higher lignin content.

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Chapter III

Effectiveness of Premium Wood Pellets as a Fuel Source for Curing Flue-cured Tobacco

Introduction

The energy intensive process of producing flue-cured tobacco has many industry leaders testing potential ways to develop a more sustainable production method for the crop (Altria, 2017 and Phillip Morris International, 2017). The curing process of flue-cured tobacco production requires large amounts of energy and is an obvious area where improvements in energy efficiency can occur. Flue-cured tobacco has a history of utilizing biomass, with wood being the original fuel used to heat curing barns. However, wood has long been replaced by oil, propane and natural gas in developed countries. The drawbacks of wood biomass when compared to fossil fuels are generally the low energy density, heterogeneity, and high moisture content (Obernberger and Thek, 2010). These drawbacks combined with the ease of use provided by fossil fuels have made curing flue-cured tobacco with biomass fuels outdated until recent societal changes have brought more awareness to carbon dioxide pollution and sustainability. Using biomass fuels has great potential to reduce the emissions from carbon dioxide (CO_2), methane (CH_4), water vapor, and nitrous oxide (N_2O) and slow climate change (Fournel et al., 2015 and Singh, 2013). Condensing biomass into a pelleted form of fuel offers resolution to the previously known downfalls of using biomass as a fuel source by creating a renewable fuel that has high energy density, low moisture content and a homogeneous size and shape (Oberberger and Thek, 2010).

Pellet burners are compact units that do not require large amounts of space to operate. In particular, wood pellet burners can be fitted into the back portion of the flue-cured tobacco bulk curing barn and attached to the heat exchanger in the cabinet by replacing the original heat exchanger with one modified to be compatible with a wood pellet burner. Attaching a wood pellet burner to an air-to-air heat exchanger and installing the combination into a bulk curing flue-cured tobacco barn is a novel idea. No information is available regarding the performance and cost associated with replacing a traditional propane burner with a premium wood pellet burner. Therefore a two-year study was conducted at Virginia Tech Southern Piedmont Agriculture Research and Extension Center located near Blackstone VA to evaluate the effectiveness of premium wood pellets as a fuel source opposed to propane or natural gas. The objectives of this study were to:

1. Evaluate the first time use of a wood pellet burner with an air-to-air heat exchanger in a bulk tobacco curing barn.
2. Calculate comparative numbers for wood pellets and propane for curing cost and CO_2 emissions.

Materials and Methods

Trials were conducted in 2016 and 2017 at the Virginia Tech Southern Piedmont Agriculture Research and Extension Center located in Blackstone VA. Tests were arranged in a completely randomized design (CRD) and were replicated four times. A paired t-test was used to statistically compare CO_2 emission, cost, and energy usage for both fuel sources. Specifically constructed bulk curing barns were utilized for this study. The 3-box Tytun ™ Elite (Tytun Ltd, Simcoe, Ontario) represent the most energy efficient barn available. One barn was equipped with a high efficiency propane burner (Riello, Mississauga, Ontario) and the second was equipped with a wood pellet burner (Kedel, Portland, Maine). Six identical flue-cured tobacco bulk boxes (81 cm length X 292 cm width X 175 cm height) were filled with 636-727 kg (depending on stalk position of harvested tobacco leaves) of identical uncured green leaf tobacco which was outsourced from local farmers. Three filled bulk boxes were placed into each barn. Both barns were equipped with a curing control system (Suretrol, Seven Springs, North Carolina) that regulates barn ventilation based on the desired wet bulb temperature setting and barn temperature based on the desired dry bulk setting. Fuel consumption was recorded for each cure in the respective barns with either a propane meter or by recording pellet consumption shown online at the website where the pellet burner is controlled. CO_2 emissions were calculated using fuel consumption records by multiplying the fuel usage (propane or wood pellets) by the fuel's emission factor which is 5.76 kg CO_2 and 0.04 kg CO_2 for propane and wood pellets respectively. After the curing cycle (displayed in Fig. 1.1) completed, the tobacco was rehydrated to approximately 16 percent moisture, removed from the barn, baled, and weighed. The weights were used in conjunction with fuel consumption to calculate curing efficiency. Tobacco quality grades were not assigned to the tobacco bales. However, tobacco quality was observed to be similar between both fuel sources.

Results and Discussion

Curing seasons consisted of four cures each. Premium wood pellet consumption was recorded for each cure as shown in Fig. 3.1. Wood pellet consumption follows similar trends in both years with 1.0 to 1.1 lbs of pellets required per pound of cured tobacco (Fig 3.2). However, the last cure of 2017 required substantially more than the other cures (1.45 lbs). Although curing tobacco in colder weather of October would be expected to utilize more fuel, ash accumulation in the heat exchanger is suspected to have impacted efficiency. Inspection of the heat exchanger at the end of the season revealed significant as build up in the combustion chamber and heat exchanger tubes (Fig. 3.3).

Pellet usage was tracked hourly throughout the entirety of each cure. Consumption rates would vary from 2.9 – 15 lbs. depending on the heated needed at that time which is determined by the barn's curing controller. During the beginning hours of the curing cycle pellet consumption was minimal. When the curing controller calls for heat the pellet burner increases pellet consumption incrementally until a peak was reached then pellet consumption drops back slightly and remain fairly constant until more heat was needed. An example of the hourly pellet consumption from the first cure in 2017 is shown in Fig. 3.4. Peaks in pellet consumption correspond with increased heat demand associated with periods of time that dampers are opened to expel moisture from the curing environment.

Comparative fuel consumption data with the propane fueled barn is illustrated in Fig. 3.5. The propane consumption and curing efficiencies noted during this study are better than more typical flue-cured tobacco barn due to using the most high efficient burner/barn combination available for this study. Fig. 3.6 displays the propane consumption of both years and also shows a fuel usage comparison of curing cycles that took place in similar times of the year. The slight differences in fuel usage could be associated with differences in stalk position of where the leaves were harvested, weather condition at the time of curing or the amount of tobacco filled in the curing boxes.

Carbon dioxide emissions and economic cost associated with bulk curing flue-cured tobacco were calculated from premium wood pellets and propane. Tables 3.1 through 3.3 show fuel consumption records, carbon dioxide emission data, and a comparison in cost associated with curing tobacco using propane and wood pellets in both 2016 and 2017 curing seasons. The interaction between fuel and year was non-significant for curing efficiency, cost, and CO_2 with cured tobacco and the data were combined over years. Curing with propane resulted in both a higher curing efficiency (*p = 0.0001*), and lower curing cost (*p = 0.0020*) than wood pellets. However, carbon dioxide emissions were substantially reduced (*p = <0.0001*) when using wood pellets. Table 3.4 shows statistical results for the complete study. Energy consumption was determined for each fuel source during individual cures (Fig. 3.7) with a trend of wood pellets requiring more energy to cure tobacco. Using wood pellets resulted in an approximate 90 percent reduction in CO_2 emissions (Fig. 3.8). Premium wood pellets on average cost $221 per metric ton while bulk price of propane varies $0.24 - 0.32 per liter. Cost of curing flue-cured tobacco was estimated using $0.32 per liter for bulk propane. Overall during the 2016 curing season, the cost of curing was found to be 4.8 cents per kg cured tobacco using premium wood pellets compared to 4.2 cents per kg cured tobacco using propane. Overall average cost of curing in 2017 using premium wood pellets and propane was found to be 5.2 cents per kg cured tobacco and 4.1 cents per kg cured tobacco respectively. Curing cost for each cure during both years is shown in Fig. 3.9. In contrast to propane, wood pellet prices tend to be relatively stable making budgeting for curing fuel expense less variable from year to year.

The heating of a bulk curing barn with a wood pellet burner on an air-to-air heat exchanger is a novel idea in the United States. Installation of the pellet storage bin and an adequate supply auger provides convenience similar to that of a propane burner. The most significant difference with a pellet burner is that the burner must remain lit rather than cycling on and off like a gas burner. In order to meet the heat demand of the barn the output of the burner is varied from 10 percent to 100 percent. The study concluded that wood pellets are a viable fuel to cure flue-cured tobacco. Currently, wood pellets are similar economically as propane. However, initial installation cost for the wood pellet burner and associated infrastructure are substantially higher than the propane counterpart. This large difference in upfront cost currently could not be paid back based on fuel prices. In order for wood pellets to be overall more economical than propane the tobacco industry must reward farmers for lower pollution emissions or a monetary price be placed on CO_2 pollution.

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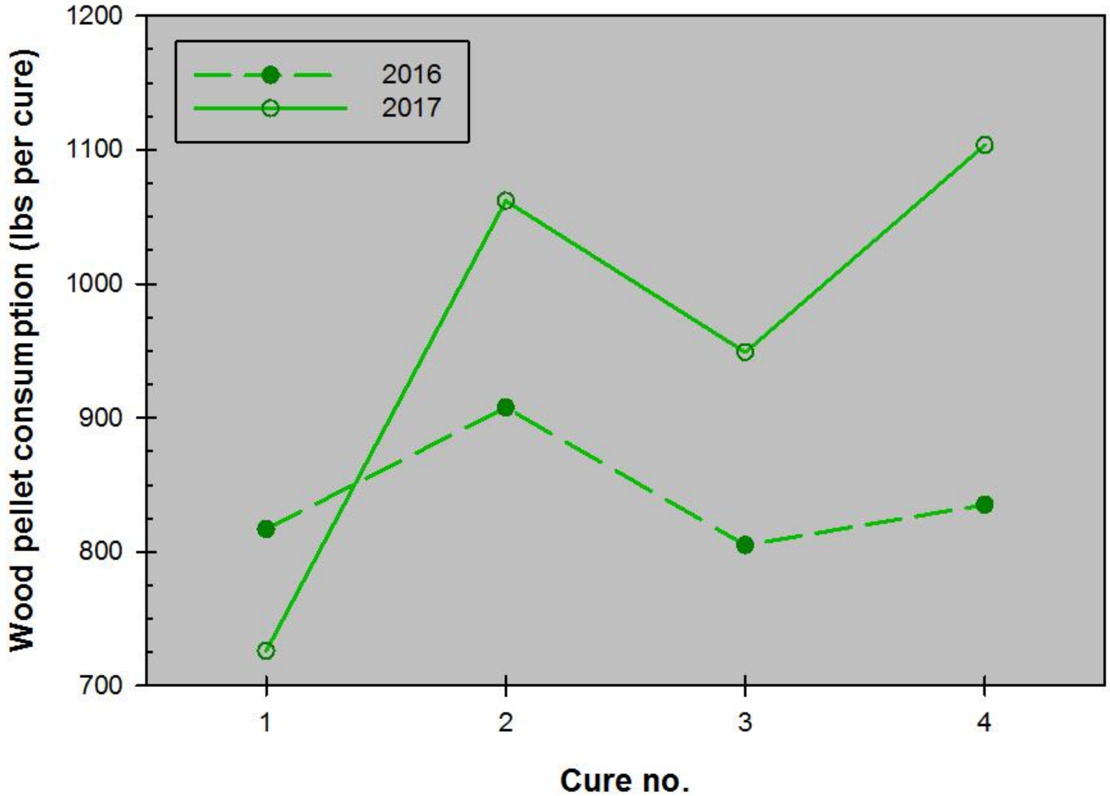

Figure 3.1. Total wood pellet consumption for 4 cures in 2016 and 4 cures in 2017.

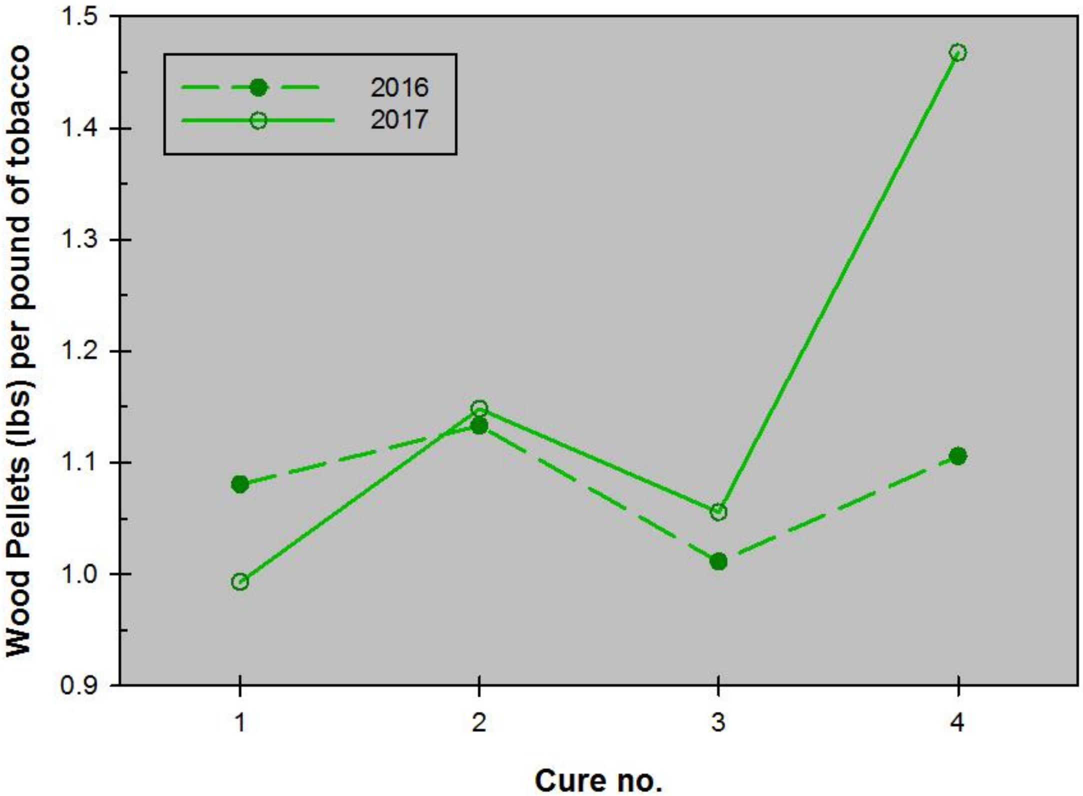

Figure 3.2. Wood pellet consumption for a pound of cured tobacco for four cures in 2016 and 2017.

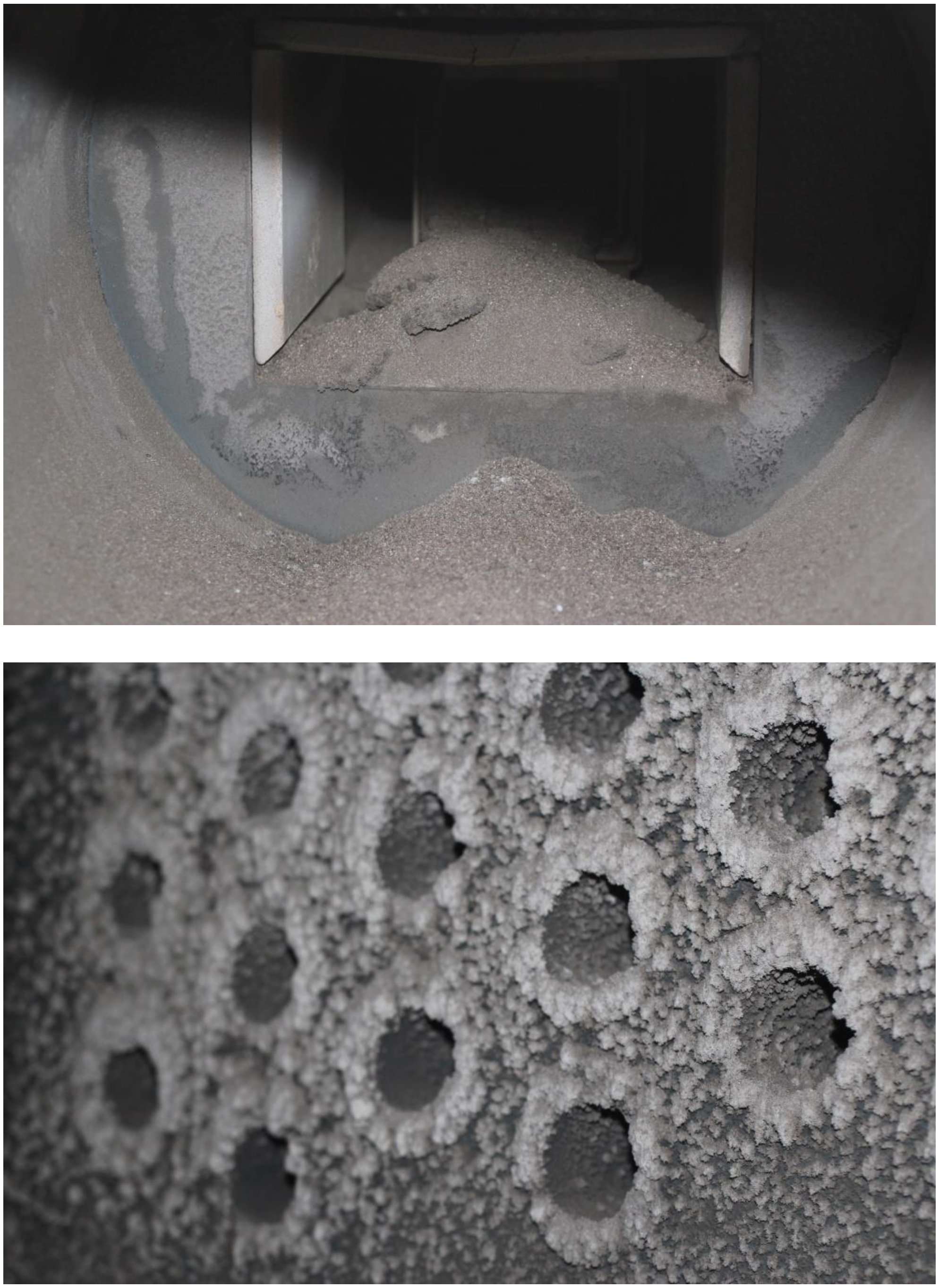

Figure 3.3. Ash build up in the heat exchanger lowers curing efficiencies and increases fuel consumption. The combustion chamber (upper) collects larger pieces of ash in close proximity to the wood pellet burner compared to the secondary tubes (lower) that generally collect the smaller fly ash particles.

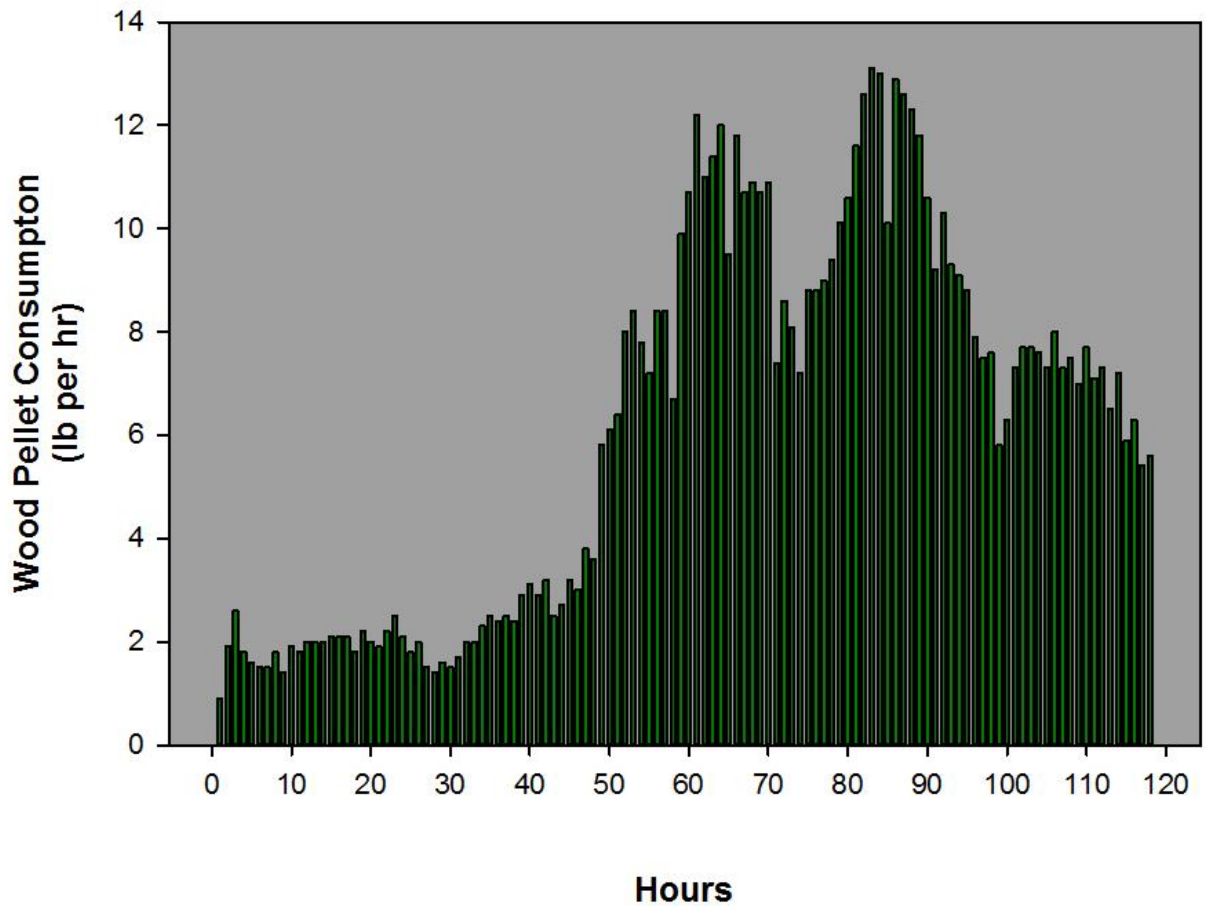

Figure 3.4. Example of hourly wood pellet consumption for cure 1 of 2017.

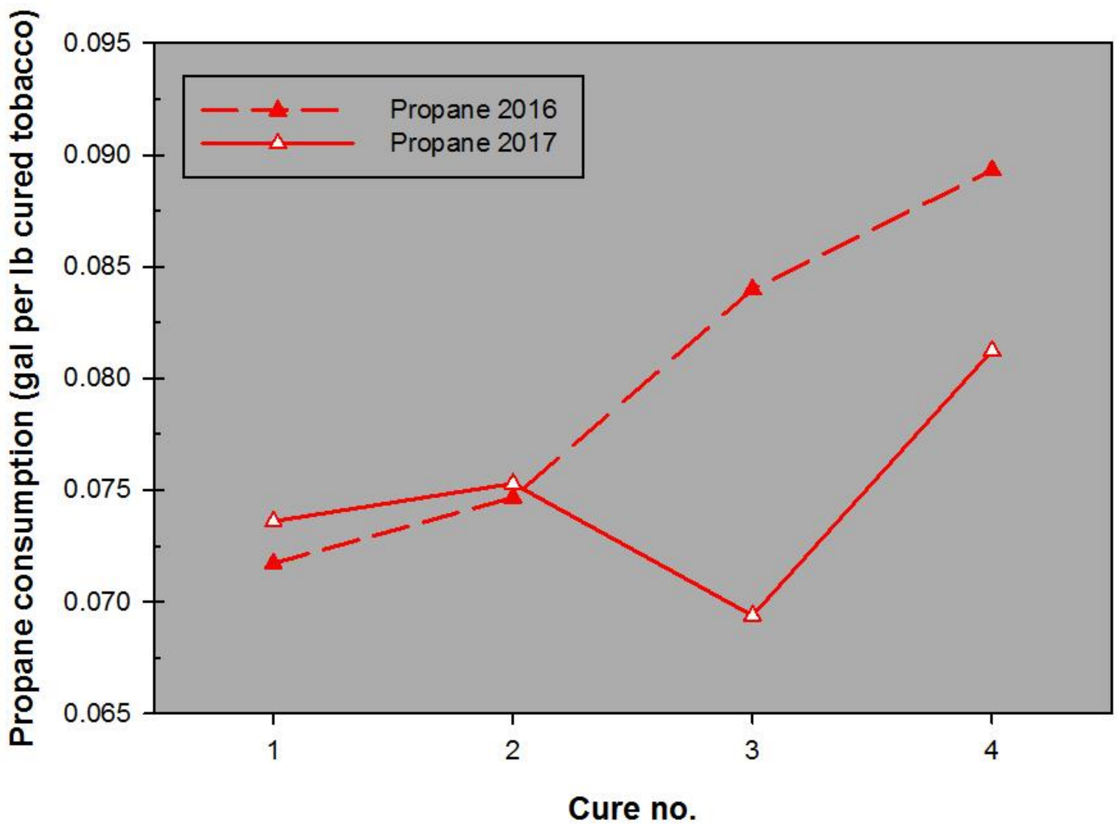

Figure 3.5. Propane consumption for a pound of cured tobacco for four cures in 2016 and 2017

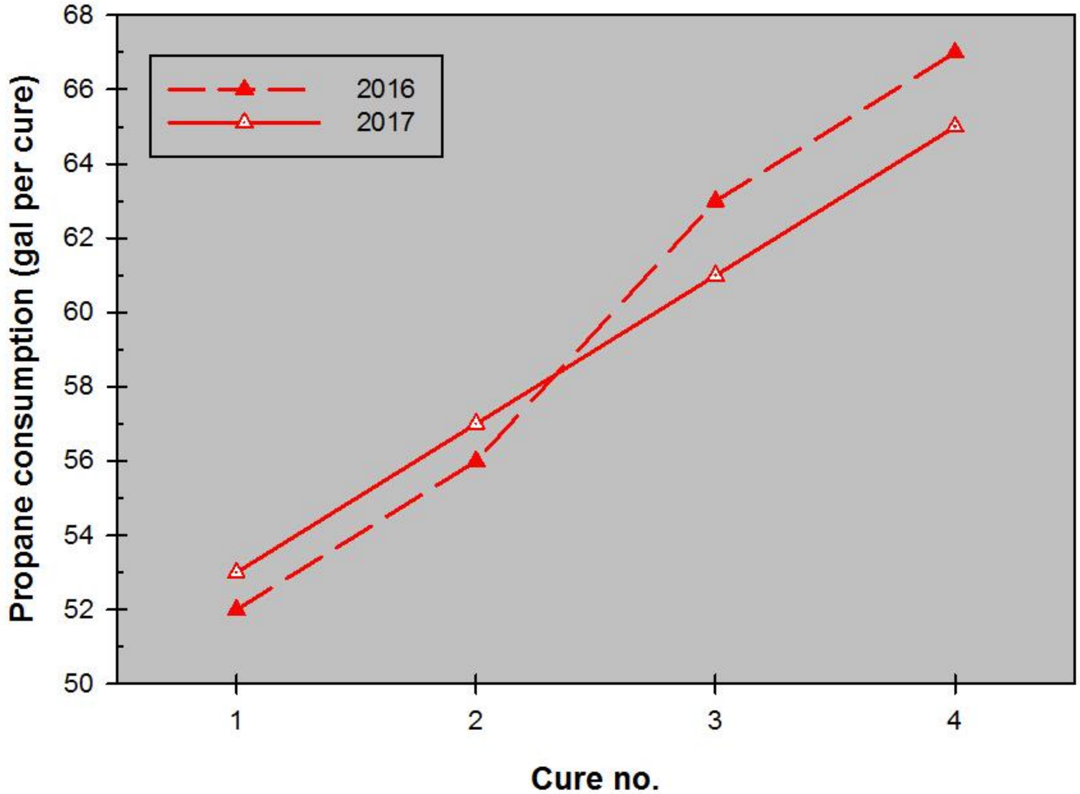

Figure 3.6. Total propane consumption for 4 cures in 2016 and 4 cures in 2017.

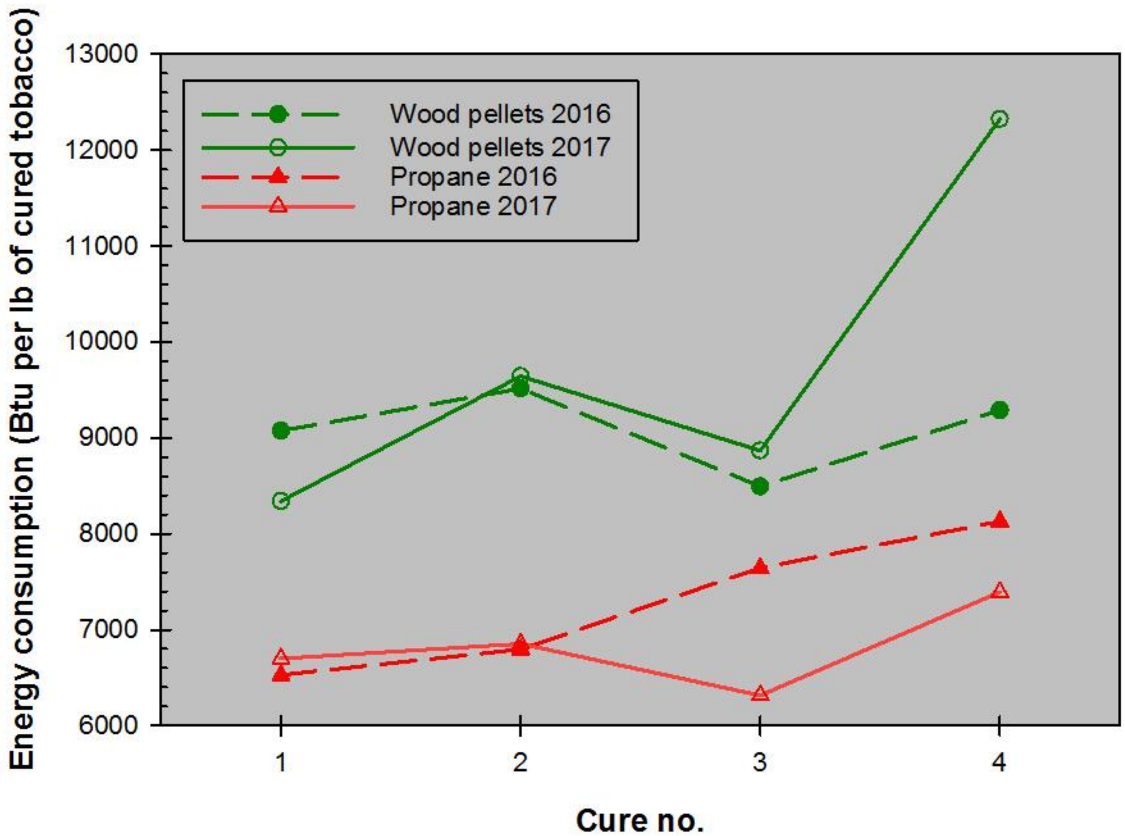

Figure 3.7. Comparison of energy consumption required to cure a pound of tobacco with wood pellets and propane for four cures each in 2016 and 2017. Energy consumption was significantly greater with wood pellets ($F = 32.88$ and $p = 0.0001$).

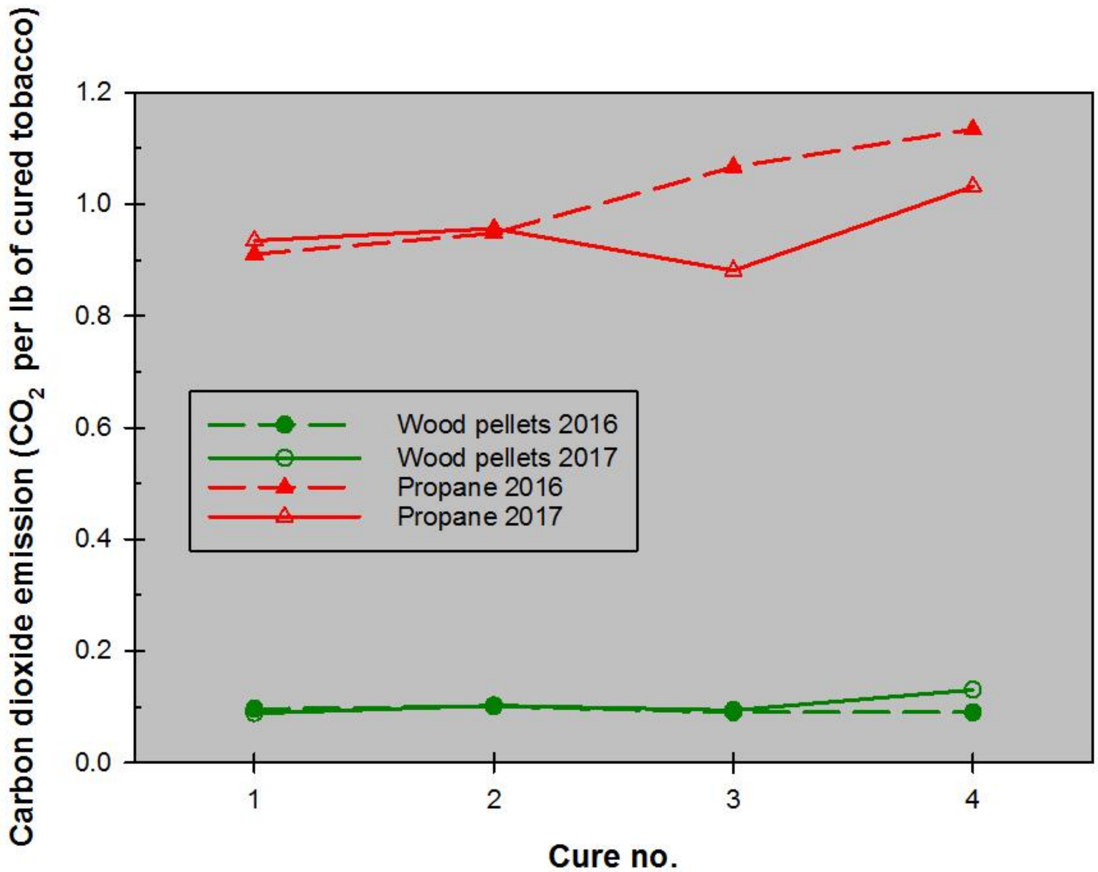

Figure 3.8. Comparison of carbon dioxide produced for four cures with wood pellets and propane in 2016 and 2017. Emissions were significantly greater for propane ($F = 967.52$ and $p = <0.0001$).

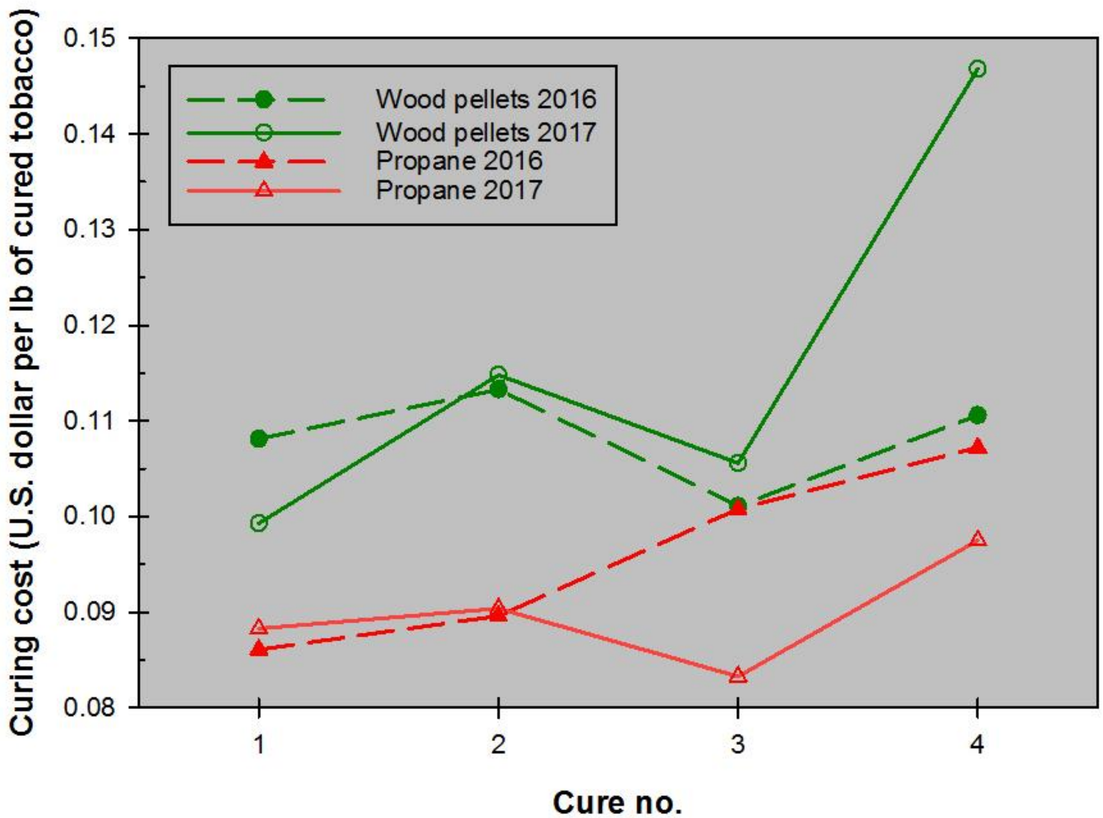

Figure 3.9. Curing cost comparison between wood pellets and propane for four cures in 2016 and 2017. Overall cost were significantly greater using wood pellets ($F = 16.25$ and $p = 0.0020$).

Table 3.1. Curing efficiency comparison for flue-cured tobacco using premium wood pellets and propane as the fuel source in 2016.

	Cure1		Cure 2		Cure 3		Cure 4	
Burner Parameters	Wood Pellet	Propane	Wood Pellet	Propane	Wood Pellet	Propane	Wood Pellet	Propane
Fuel usage (lb or gal)	817	52	908	56	805	63	835	67
Tobacco cured (lb)	756	725	801	750	796	750	755	750
Fuel usage per lb	1.08	0.07	1.13	0.07	1.01	0.08	1.11	0.09
Btu[1] per lb	9077	6527	9518	6795	8494	7644	9290	8129
CO_2 per lb	0.10	0.9	0.10	0.9	0.09	1.1	0.10	1.1
Cost per lb	0.11	0.09	0.11	0.09	0.10	0.10	0.11	0.10

[1] 1 gal propane =91,000 Btu and 1 lb wood pellet = 8500 Btu

Table 3.2. Curing efficiency comparison for flue-cured tobacco using premium wood pellets and propane as the fuel source in 2017.

	Cure 1		Cure 2		Cure 3		Cure 4	
Burner Parameters	Wood Pellet	Propane	Wood Pellet	Propane	Wood Pellet	Propane	Wood Pellet	Propane
Fuel Usage (lb or gal)	726	53	1062	57	949	61	1104	65
Tobacco Cured (lb)	731	720	925	757	899	879	752	800
Fuel Usage per lb	0.99	0.07	1.15	0.08	1.06	0.06	1.47	0.08
Btu[1] per lb	8341	6699	9645	6852	8867	6315	12479	7394
CO_2 per lb	0.09	0.9	0.10	1.0	0.09	0.8	0.13	1.0
Cost per lb	0.10	0.09	0.11	0.09	0.11	0.08	0.15	0.10

[1]1 gal propane =91,000 Btu and 1 lb wood pellet = 8500 Btu

Table 3.3. Curing efficiency average comparison for similar flue-cured tobacco using premium wood pellets and propane as the fuel source during 2016, 2017, and overall.

Burner Parameters	2016 Wood Pellet	2016 Propane	2017 Wood Pellet	2017 Propane	Total Average Wood Pellet	Total Average Propane
Fuel Usage (lb or gal)	842	60	960	59	900	59
Tobacco Cured (lb)	777	744	827	789	802	766
Fuel Usage per lb	1.08	0.08	1.17	0.07	1.1	0.08
Btu[1] per lb	9095	7274	9833	6815	9464	7044
CO_2 per lb	0.1	1.0	0.1	0.9	0.1	1.0
Cost ($) per lb	0.11	0.10	0.12	0.09	0.11	0.09

[1]1 gal propane =91,000 Btu and 1 lb wood pellet = 8500 Btu

Table 3.4. Comparative fuel consumption efficiency data for a wood pellet burner and a propane burner during 2016 and 2017.

Burner Parameters	Burner Type			
2016	Average of Four Cures Each Year			
	Wood Pellet	Propane		
Btu per lb	9095	7274		
Cost per lb	0.108	0.096		
CO_2 per lb	0.094	1.015		
2017	Average of Four Cures Each Year			
	Wood Pellet	Propane		
Btu per lb	9833	6815		
Cost per lb	0.116	0.09		
CO_2 per lb	0.103	0.951		
Combined Years	Average of All Eight Cures			
	Wood Pellet	Propane	F-Value	Prob. > F
Btu per lb	9469	7044	32.88	0.0001
Cost per lb	0.112	0.093	16.25	0.0020
Co_2 per lb	0.098	0.983	967.54	<0.0001

Chapter IV

The Effect of Lignin Levels in Biomass Fuel Crops on Pellet Durability and Heating Value

Introduction

The energy used in the production of flue-cured tobacco is significant especially during the curing process. Industry leaders strive to lower the environmental footprint associated with flue-cured tobacco production (Altria 2017 and Phillip Morris International 2017). The use of renewable fuels for curing flue-cured tobacco is a possible way to lower carbon dioxide emissions therefore lowering the environmental footprint of the crop (Fournel et al., 2015). Biomass can be utilized as a fuel source in different forms such as ground material, chips, bricks or pellets. Pelleted biomass has advantages over ground material such as benefits in combustion, transportation, storage, high energy content and recovery capacity (El Bassam, 2010). Because of these benefits biomass pellets may be a suitable fuel source for curing flue-cured tobacco.

Understanding how to produce high quality pellets in a cost effective manner from summer annual grasses is necessary in the development of a reliable alternative energy source. In order to maintain a high quality fuel, parameters such as bulk density, pellet durability and heating potential must meet specifications. Lignin is naturally occurring in most plant material and is a generic term referring to a large group of aromatic polymers that resulted from the oxidative combinatorial coupling of 4-hydroxyphenylpropanoids (Boerjan et al., 2003; Ralph et al., 2004). Lignin acts as naturally occurring glue in biomass and improves binding characteristics of biomass pellets due to the thermosetting properties associated with lignin (Mani et al. 2006a and Mani et al., 2006b). Podder et al., (2014) and Demirbas (2001) found that lignin leads to higher heating values in pellets made from biomass, therefore knowing how different levels of lignin within summer annual grasses grown specifically for pelleting effect heating value is important when determining the effectiveness of biomass pellets as a fuel source. Brown mid rib (BMR) is a trait developed in forages that lowers lignin levels in order to produce a higher quality feed. While lower levels of lignin may be desirable for livestock feeding (Ball et al., 2015), perhaps lower levels in cellulosic materials may adversely impact pellet production and quality.

The positive attributes of lignin associated with biomass fuel pellets create the necessity of understanding how summer annual grasses with normal (NBMR) and reduced (BMR) lignin content effects pellet durability and heating value of biomass fuel pellets produced form these crops. A two-year study was performed at the Virginia Tech Southern Piedmont Agriculture Research and Extension Center located near Blackstone VA to evaluate on-farm biomass fuel pellet production from summer annual grasses with both BMR and NBMR traits.

Materials and Methods

Trials were arranged in a completely randomized block design (CRBD) and conducted in the 2016 and 2017 growing seasons. ANOVA tests were used to statistically analyze results of the test. Biomass of traditional and BMR pearl millet and sorghum-sudangrass varieties were harvested for the study described in Chapter 5. and kept for pellet production. The harvested materials were dried to 12-15 % moisture in conventional curing boxes in a tobacco barn for convenience sake rather than allowing to dry in the field

In preparation for pelleting the biomass was ground with a 30 horse power (hp) electric powered hammer mill (Fig 4.1) equipped with a cyclone separator and 0.635 cm screen and stored in mini-bulk bags. The ground biomass was pelleted with a “Make Your Own Pellets” power take off (PTO) powered flat die pellet mill (Fig. 4.2) equipped with 2 rollers, 0.632 cm die holes and a 2.54 cm thick die (Fig. 4.3). During the pelleting process, the pellet mill die was operated at a plate temperature ranging from 93-107^{o} C. and pellets were allowed to air cool on a tarp until ambient temperature was reached and pellets hardened. A 9 kg sample of pellets was collected for testing in the Pellet Fuel Testing Lab at the University of Maine. Pellets were tested according to Pellet Fuel Institute standards and compared to standards set for premium wood pellets. Parameters covered under Pellet Fuel Institute standards include bulk density, diameter, pellet durability index (PDI), fine, inorganic ash, length, moisture, chloride and heating value, measured in British Thermal Units (Btu).

Results and discussion

The results from the 16 samples of pellets sent to the University of Maine fuel pellet testing lab showed that overall densified biomass fuel pellets produced from pearl millet and sorghum-sudangrass did not generally meet the standards of premium wood pellets. Out of the nine parameters being tested, diameter and length were the only two were consistently acceptable throughout the 16 samples analyzed. The amount of fines was acceptable in all samples analyzed excluding one which had a tenfold increase compared to the others. This is believed to be caused from sampling error after the pellets had cooled. The sample should have been screened more carefully to prevent the incorporation of fines. No samples of pellets produced for testing were acceptable within inorganic ash, chloride or heating value. The criterion for bulk density was met in eight samples, PDI was met in five samples and moisture was met in eight of the samples.

Brown mid-rib and non-brown mid-rib varieties were compared in order to determine the effect lignin has on PDI and heating values. The interaction of harvest x variety was not significant ($p = 0.9997$). as well as the interaction between grass type and BMR ($p = 0.8093$).

PDI was not significantly affected (*p = 0.8346*) by the presence of the BMR trait. However, heating value was increased (*p = 0.0419*) with NBMR species which was expected due to increased amounts of lignin. Ash content was lower with sorghum-sudangrass (*p = 0.0008*) opposed to pearl millet. Results for the pellets made on-farm in some cases coincided with what was expected, however the validity of these results is questionable. The process of making pellets required a learning period in order to refine the protocol of producing these pellets. In order for this information to be more accurate more replications of this work is needed. These results could reflect flaws or irregularities in the pelleting process such as pellet mill temperature change, increased moisture content from prolonged exposer to humid ambient conditions, or not allowing finished pellets to reach adequate temperature before removal from the pellet mill. The time period between drying the different varieties, grinding and storing the material in large bulk bags, and making the pellets was often one or two weeks in length. During this storage period the ground material collected moisture from the air. Also another factor that could have affected the pellet analysis was the conditions of the pellet press during the pellet making process. The pellet mill would change temperature fairly rapidly depending on the moisture content of the material being processed making it difficult keeping the pellet mill consistently around the desired 93-103^{o} C temperature range.

The biomass pellet test results also showed that chloride levels greatly exceeded the standards for premium wood pellets (< 300 ppm). Chloride results showed non-significant (*p = 0.8093*) interaction between grass and BMR trait. However, sorghum-sudangrass varieties produced pellets with lower (*p = 0.0260*) chloride levels that pearl millet varieties. The reasons behind increased chloride levels within biomass fuel pellets are not clear however the chloride level results from these tests coincide with what is expected according to literature (Obernberger and Thek 2010). Harvest 1 2017 was the best sample of pellets sent to the lab for testing. The moisture and bulk density levels were better in this set than the other three sets. This is believed to be caused by better moisture content control of the material being pelleted. Producing pellets from summer annual grasses with a flat die pellet mill was a learning process. Each additional production process resulted in a better understanding of how to make pellets. During production of the last sample the grass was not removed from the drying barn until it could be immediately ground and pelleted. Because of this, the grass did not have time to absorb moisture from the air which is why the moisture content was consistently lower in this sample than others. Developing a protocol that refines the timeframe where un-pelleted feedstock is exposed to moisture in the air is necessary to control the moisture content of the finalized pellets. Using a proper protocol could result in pellets consistently meeting the moisture level requirement. Biomass pellet production capabilities were limited using an electric hammer mill paired with a flat die pellet mill. Substantial numbers of man hours were necessary to yield a limited amount of pellets. The inefficiency of biomass fuel pellet production on-farm causes determining an accurate cost estimate to be difficult. The pellets produced were inferior to premium wood pellets in both physical and chemical properties. However, differences in the feedstock used to produce premium wood pellets and biomass fuel pellets are notable and the ability to produce fuel pellets from pearl millet and sorghum-sudangrass that are equal to premium wood pellets could be limited. Incorporating new technologies to accommodate the differences in premium wood pellets and biomass pellets such as higher chloride and ash content could be a more viable option for utilizing biomass pellets as a fuel source.

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Figure 4.1. The 30 hp electric hammer mill shown was necessary to grind the biomass into a consistent size in order to be pelleted properly.

Figure 4.2. The PTO powered flat die pellet mill used to produce the biomass pellets on-farm. Ground biomass is fed into the top and compressed pellets fall from the open chute.

Figure 4.3. The inside of the PTO powered flat die pellet mill. The flat die plate in the bottom rotates against both rollers to create friction and heat. The rollers also force the ground material through the holes in order to create the cylindrical biomass pellets.

Chapter V

Nitrogen Effect on Yield of Biomass Fuel Crops for On-farm Pelleting

Introduction

The curing process of flue-cured tobacco requires significant energy to provide the necessary heat for drying. Propane is the most common fuel used. Given production levels of 23,000 and 285,000 metric tons in Virginia and the U.S. overall respectively, approximately 19 and 189 million l. of propane were consumed respectively. Such fuel usage would result in corresponding CO_2 emissions of 29 and 201 metric tons (U.S. Energy Information Administration, 2016). Reducing the environmental footprint of tobacco production is an industry concern (Altria 2017 and Phillip Morris International 2017). Improving tobacco curing efficiencies and utilizing renewable fuels for curing are two means of doing so. In addition to reducing the carbon footprint associated with flue-cured tobacco, using renewable fuel sources that can be grown on-farm in rotation with other crops could increase the tobacco production capabilities of international regions where the infrastructure to supply fossil fuels (propane and natural gas) is insufficient. Curing flue-cured tobacco is the part of the production process where significant interest has been placed on using renewable fuel sources since it is the most energy extensive part of the production process. El Bassam (2010) recognizes that utilizing raw plant material for energy offers agricultural production a means to be reorganized towards a more environmentally conscious system. Reorganizing agricultural production to incorporate biomass fuels becomes more beneficial when considering price increases and fluctuations of fossil fuels in conjunction with social unrest in major fossil fuel producing regions. These factors lead to increased interest in using on-farm produced biomass fuel to reduce the carbon footprint of curing flue-cured tobacco.

Numerous agricultural crops may be considered for production of biomass fuels and Fike et al. (2013) discussed the factors that would be considered. Once a suitable crop is selected for a specific farm, the best production practices must be decided upon for the most profitable production. Nitrogen (N) fertilization is a common production factor impacting the yield of forage crops that may be used for biomass production (Shahin et al. 2013). A two-year study was conducted to evaluate the yield response of pearl millet and sorghum-sudangrass to N fertilization.

Material and Methods

Field trials were conducted in 2016 and 2017 at the Virginia Tech Southern Piedmont Agriculture Research and Extension Center in Blackstone, Va. Two different field sites were used but the soil type for both sites was an Appling course sandy loam. Trials were seeded during the second week in June in 2016 and the first week in May in 2017. Treatment variables evaluated included two pearl millet and sorghum-sudangrass varieties with three N fertilization rates. The biomass crops included:

1. Pearl millet without brown midrib trait (Var. SS635, Southern States Corp., Richmond VA)
2. Pearl millet with brown midrib trait (Var. SS1562, Southern States Corp., Richmond VA)
3. Sorghum-sudangrass without brown midrib trait (Var. SS211, Southern States Corp., Richmond VA)
4. Sorghum-sudangrass with brown midrib trait (Var. SS220, Southern States Corp., Richmond VA)

Nitrogen fertilizer rates evaluated were 0, 56, and 112 kg N per ha with N being supplied from ammonium nitrate. Plots 1.8 m wide and 9.1 m long were arranged in a randomized complete block design (RCB) with 6 replications. Field preparation included an applications of Glyphosate at 2.3 l per ha followed by passes with a disk harrow and field cultivator to prepare an adequate seed bed. Dry soil conditions in 2016 required the use of a Brillion cultipacker (Landoll Marysville, Kansas) to firm the soil before seeding. Plots were seeded with a research plot seeder (ALMACO Nevada, Iowa). Fertilizer was hand applied the day of planting by evenly broadcast spreading premeasured bags of fertilizer across the whole pot.

The crops were harvested at full maturity (>75% of plants had produced heads) with a WINTERSTEIGER (Model Cibus F) research forage harvester. The harvester has the capability to harvest, weigh and drop the biomass into a pile on the ground. Green weights from each plot were recorded. A hand sample from each plot was taken to determine dry matter (DM) content at harvest. After each plot was sampled the remaining biomass was collected and compiled into 4 total bulk tobacco curing boxes according to variety (one box per variety).

Results and Discussion

Nitrogen fertilization of both pearl millet and sorghum-sudangrass varieties resulted in increased yields in both seasons. Plots fertilized with 112 kg N per ha provided the highest yields of all four varieties for the first harvest of 2016 as well as the second harvest with the exception of SS635. This lower yield may have been the result of sampling irregularities with high incidences of weeds in some plots. A similar response in yield to increase N fertilization was observed in 2017. Yields of sorghum-sudangrass generally tended to exceed pearl millet and may have been the result of being more competitive against dry weather conditions and weed pressure. Analysis of the total yield data shows a non-significant ($p = 0.9299$) interaction between year and N-rate. Results showed 2017 yielding significantly higher ($p = <0.0001$) than 2016. Increased nitrogen fertilization resulted in increased ($p = 0.0008$) yields overall. Statistics for combined years are shown in Fig 5.1.

Results of this study pretty much follow what would be expected. The 4 varieties of summer annual grasses positively responded to N fertilization. The higher N application rates (with the exception of SS635 in harvest 2 of 2016) showed increased yields opposed to lower N rates. It was observed in this study that limited water availability soon after planting or harvesting reduces yield and allows for much more weed growth to occur. Plots fertilized with 0 kg N per ha resulted in yield reduction; although such a minimal input approach to production would represent a lower carbon footprint management practice for producing these biomass fuels as well as similar production practices within an area that has limited fertilization resources.

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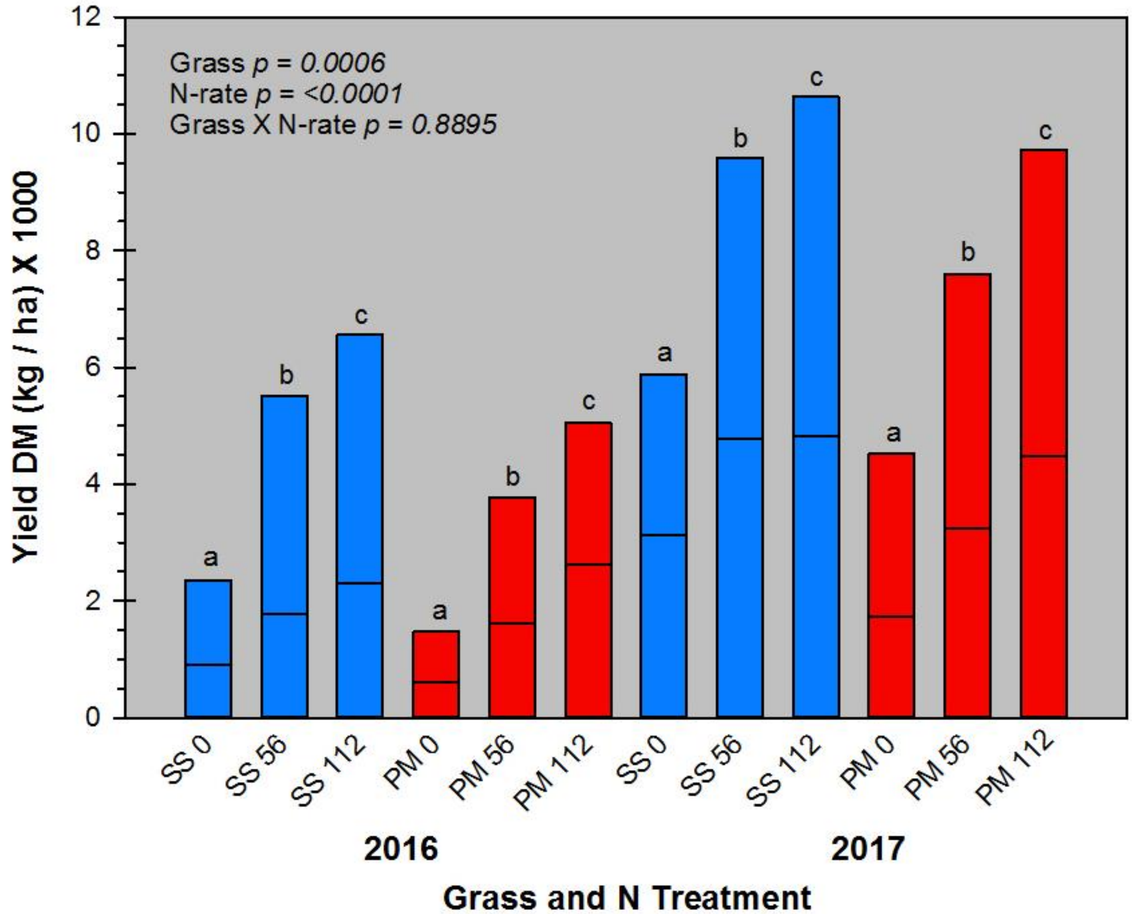

Figure 5.1. Total yield shown for two varieties each for both sorghum-sudangrass and pearl millet varieties with each N rate in 2016 and 2017. Lower portions of the bars depict yields from the first harvest and upper portions represent yields from the second harvest. Bars with the same letter within a forage species and year are not different according to Fisher's projected least significant difference ($p = 0.05$).

Chapter VI

Harvest Frequency Effect on Yield of Biomass Fuel Crops for On-farm Pelleting

Introduction

The environmental footprint of tobacco production is a major focus of the tobacco industry (Altria, 2017 and Phillip Morris International 2017). Curing flue-cured tobacco is an energy intensive process that traditionally requires large amounts of propane or natural gas to provide the heat needed to dry tobacco leaves. These large quantities (19 and 189 M l propane in Virginia and the overall U.S. tobacco producing region, respectively during 2016) cause large amounts of carbon dioxide (CO_2) to be emitted into the atmosphere (29,000 and 288,000 metric tons. respectively) (U.S. Energy Information Administration, 2016). The use of renewable and sustainable energies is discussed frequently as a means of lowering the environmental pollution caused by producing tobacco.

Growing summer annual grasses to provide the biomass fuel to cure flue-cured tobacco on farm is one practice that could potentially lower the environmental footprint of tobacco production (Fournel *et al.,* 2015). Biomass is a renewable heat source that may be used regardless of the size of demanded (El Bassam, 2010). Producing biomass fuel pellets on-farm requires a constant supply of consistent biomass feedstock. (Obernberger & Thek 2010). Summer annual grasses, including sorghum-sudangrass and pearl millet, have potential as bio-fuel crops because they can be grown in many environments, produce high yields, and can be processed into uniform biomass fuel pellets (El Bassam, 2010). A common practice for growing summer annuals to produce forage for livestock is to harvest the crop in intervals around a plant height of 1 m (Teustch 2009). This harvesting practice balances forage quality and digestibility with overall yield. However, the objective of growing sorghum-sudangrass and pearl millet as a fuel crop would be to maximize the total biomass yield.

The importance of knowing which harvesting frequency practice yields the most biomass for commonly used summer annual grasses is critical. Therefore, a two-year study was conducted to evaluate harvest practices for these summer annual grasses. The objective of this study was to determine the effect of harvest frequency on the overall yield of sorgum-sudangrass and pearl millet used for the production of biomass fuel pellets.

Materials and Methods

Field trials were conducted in summers of 2016 and 2017 at the Virginia Tech Southern Piedmont Agriculture Research and Extension Center in Blackstone. VA. Two separate fields were used that consisted mostly of Durham coarse sandy loam phase soil type but also contained a small portion of made land. One test was seeded with a Southern States variety, SS635 (pearl millet) at 28 kg per ha. The second test was seeded with Southern States' SS211 (Sorghum-sudangrass) at a rate of 56 kg per ha. Plots were planted on June 7 and 8 of 2016. The 2017 test was planted using the same seeding rates as 2016, however the test was planted about a month earlier on May 2. During the 2016 season, 15-0-15 fertilizer was applied at a rate of 560 kg per ha and $CaCO_3$ lime was applied at 3000 kg per ha. Fertilizer and lime treatments were applied with a Gandy spreader. Fertilizer was split applied in 2017, first, 44 kg N per ha was broadcast sprayed as 30 UAN on May 19, and followed by an application of 235 kg per ha 10-0-46 granular fertilizer on May 22. Prior to seeding in both seasons, the field was broadcast sprayed with a glyphosate treatment of 2.34 l per ha to kill all existing vegetation. Tests were planted both years using a no-till seed drill (Great Plains Manufacturing, Salina, KS). Plots were 4.9 m wide and 30.5 m long. Separate plantings of sorghum-sudangrass and pearl millet were made at the test site and the direct harvest comparisons of the two were not made. Treatments were arranged in a completely randomized design (CRD) and replicated three times. Harvest treatments were (1) harvest at 1 m height or (2) harvest at full maturity (> 75% producing seed heads). All plots were harvested at a cutting height of 10 cm. A cleanup cutting was made to biomass grasses at the end of the season on all plots which was used in calculating total yield.

Plots were harvested with conventional hay equipment. A disc mower (Bush Hog, Selma, Alabama) and disc bine (New Holland Agriculture, New Holland, Pennsylvania) were used to cut the vegetation of each plots. The grasses were spread across the plot to help drying with a hay tedder (Kuhn North America, Brodhead, Wisconsin), windrowed using either a roll-bar rake (Oak Brook, Illinois) or a v-rake (New Holland Agriculture, New Holland, Pennsylvania) and baled with a net wrap round baler (New Holland Agriculture, New Holland, Pennsylvania). Prior to the grass being baled a sample was taken and weighed to determine moisture content. Each plot produced one bale which was weighed and the results were extrapolated to calculate yield of dry matter (DM) per acre.

Results and Discussion

Trials conducted in 2016 yielded three cutting dates overall. The first cutting (1 m height) was conducted on July, 7 in both the sorghum-sudangrass and pearl millet tests All plots in each test were harvested during the second cutting on August, 10. During this harvest the full maturity plots had reached the proper growth and the 1 m plots had regrown and were ready for harvesting. One final cutting was taken from all plots on October, 13 to remove the remaining biomass at the end of the season. The total harvested dry matter from the two or three cuttings, depending on the maturity stage, was added together and showed that full maturity sorghum-sudangrass yielded the highest and 1 m multiple harvest pearl millet yielded the lowest.

Trials during the 2017 growing season contained four individual cutting dates. 1 m height sorghum-sudangrass were cut on June, 26. Pearl millet harvested at 1 m and full maturity sorghum-sudangrass were cut on July, 17. On July, 31 full maturity pearl millet and 1 m sorghum-sudangrass were harvested. One final cutting was done on September, 19 on all plots with the exception of plot 1 to remove the final biomass from the plots for the season. Plot 1 was not harvested on this cutting due to there being an extensive amount of weeds incorporated in the plot which would have given a false yield figure.

The sorghum-sudangrass test showed non-significant interaction between year and treatment ($p = 0.4936$), however 2017 resulted in significantly ($p = 0.0071$) higher yields than 2016. Harvesting practices were shown to impact yield in both 2016 ($p = 0.0013$) and 2017 ($p = 0.0015$). The sorghum-sudangrass test produced similar results across each year and consistently showed full maturity harvest produced higher yields. However, pearl millet tests produced significant interaction between treatment and year ($p = <0.0001$) but year did not affect yield ($p = 0.9629$). Both 2016 ($p = 0.0233$) and 2017 ($p = 0.0107$) resulted in yield being significantly affected by harvest frequency. Results for the pearl millet test showed contradicting information. However, the full maturity harvest in believed to produce higher yields. During 2017 the pearl millet stands suffered from low germination and growth throughout the entirety of the growing season. The low germination and poor growth are believed to have affected results in 2017. Figure 6.1 displays yield information and treatment significance for both sorghum-sudangrass and pearl millet across both years.

Numerically sorghum-sudangrass yields were higher than pearl millet yields across both growing seasons when comparing similar harvest treatments. During the first cutting of 2016 (1 m height plots) the biomass received a rainfall event which delayed the field drying of the plots.

This also caused increased tractor traffic on the plots which is thought to be the main reason for lower yields in the later harvest. In all cuttings across both years it was observed that equipment traffic impacted plan stands. In the areas where the tires ran over the crops there was minimal regrowth, which affected the total plot yield, especially in the 1 m harvest height plots where there was an additional cutting.

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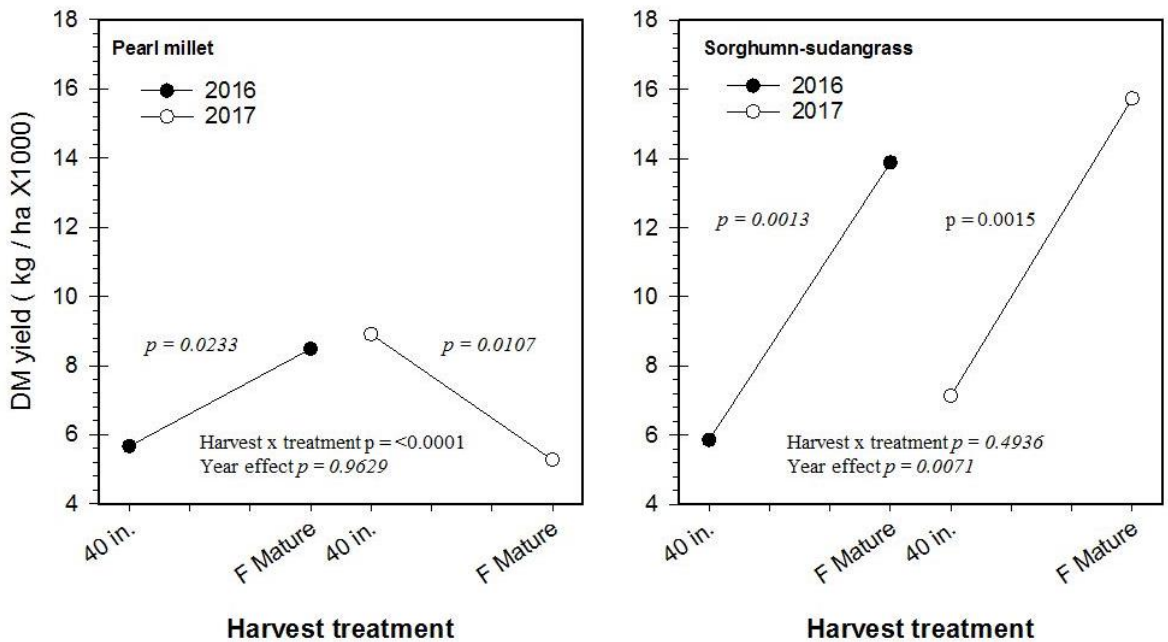

Figure 6.1. Harvest frequency effect on yield for both pearl millet (left) and sorghum-sudangrass (right) during 2016 and 2017.

Chapter VII

Conclusions and Further Direction

Premium wood pellet burner

The first time use of a wood pellet burner with an air-to-air heat exchanger in a bulk curing tobacco barn provided a viable option for curing flue-cured tobacco using a renewable fuel. Burner operation was similar to a propane burner except the need to periodically clean the ash from the heat exchanger. Excessive accumulation in both the combustion chamber and secondary tubes impacts heat transfer and reduces heat exchanger efficiency. However, this process could be automated on a commercial heat exchanger. An additional difference between a pellet burner and a gas burner is that the pellet unit continuously burns rather than cycling on and off. Our burner reduced power output to 10 percent when the barn did not require heat. The necessity of the burner to operate this way undoubtedly impacted fuel consumptions early in the curing cycle when heat requirements are limited.

Utilizing premium wood pellet in conjunction with a high efficiency burner offer several advantages over traditional propane burners. The tobacco industry has the goal of reducing the environmental footprint of tobacco production. Renewable fuel alternatives to the use of fossil fuels for curing tobacco would have a substantial impact on the carbon emissions. Wood pellets are an attractive renewable fuel source since they are a commercially available commodity that can be readily delivered to the farm and readily stored and handled in a convenient manner. Unlike wood chips or sawdust heated hot water boiler systems that require significant changes to infrastructure and tie multiple barns together, the use of wood pellet fuel with individual burners allows for incremental adoption and individual barn operation. During this study the high efficiency wood pellet burner did not exceed the curing efficiency values collected from a prototype high efficiency propane burner, however using a wood pellet burner does provide the opportunity for tobacco curing efficiency values exceeding that of predominantly used propane technology which are less efficient. However, additional work is necessary to improve ash removal from the heat exchanger to improve the system efficiency and convenience for the grower. Perhaps the biggest obstacle to adoption of wood pellet burners is the investment cost in comparison to propane. However, this could be offset by preference or premiums provided by the industry to growers making such investments to utilize renewable fuels.

Premium wood pellets offer a low carbon footprint fuel source that can be used in many applications. Obernberger and Thek (2010) stated that carbon dioxide emissions from biomass can be “regarded as carbon neutral” due to the CO_2 emitted during combustion is taken up again during the plants regrowth. Carbon neutrality regarding premium wood pellets refers to the thermal utilization of pellets not the entire carbon life cycle analysis. Premium wood pellets are still a source for carbon pollution. This pollution comes from the fuel supply necessary to transport the biomass in all forms as well as from the auxiliary energy needed during the pelleting process. The sources of auxiliary pollution can be categorized into two main sectors; harvesting the biomass in the forest and pellet production. Diesel fuel usage and electricity account for the most CO_2 production during the two major sectors of complete life cycle analysis of wood pellets respectively. Electricity requirements throughout the pellet production system have the highest impact on the environmental footprint of wood pellets. The environmental footprint of wood pellets considered through a life cycle analysis is still considerably lower than fossil fuel counterparts. According to literature, the carbon pollution of wood pellets is 10 percent of fossil fuels. Therefore, premium wood pellets have a drastically reduced environmental footprint opposed to fossil fuels even if wood pellets are not completely carbon neutral.

Carbon dioxide emission reductions were noted during the comparison of wood pellets and propane as fuel sources for curing flue-cured tobacco. Increased curing costs were associated with wood pellets but the significant reduction in CO_2 emission could offset this. Additionally, curing costs for propane were calculated using a current lower price with an ultra-high efficient propane burner. Comparisons to a more typical propane burner and increases in price similar to previous years would make wood pellets equally or more cost effective than propane. Also, the U.S. currently does not have a cost associated with CO_2 emissions unlike many European countries where a carbon credit system is in place. Under circumstances similar to European countries, reduced CO_2 pollution from wood pellets could directly correlate with monetary savings. Specifically regarding tobacco curing, if industry leaders developed a growing grading system there could be producer benefits for reduced environmental footprints such as premium price on tobacco sales and increased contracts amounts.

On-farm biomass pellet production

Producing biomass fuel pellets from sorghum-sudangrass and pearl millet is possible on farm. However, producing consistent quality pellets in a timely manner using an electric hammer mill and PTO-powered flat die pellet mill proved to be difficult. Handling the material created considerable quantities of dust that reduced the amount of feedstock available for pelleting all the while creating a difficult working environment. Mechanized self-contained pellet production would improve production but would not be practical for on-farm use.

Physical parameters of the biomass pellets produced in this study did meet the standards for premium wood pellets. However, the chemical parameters (ash, chloride and heating value) cannot meet premium wood pellet standards. The heating value was approximately 10 percent lower but that could be offset by pellet cost using biomass crops. High ash and chloride levels of the biomass pellets were more problematic. High efficiency wood pellet burners are not equipped to handle excessive quantities of ash. The high chloride levels of the biomass pellets could be expected (EL Bassam 2010) and is an issue for both potential corrosion to the heat exchanger and negative emission production. In the U.S. where premium quality wood pellets are available at a consistent price, the on-farm production of biomass pellets is likely not economically viable. In developing countries lacking wood pellets, the use of biomass pellets would be a reasonable option.

Best management practices for growing biomass fuel crops

Sorghum-sudangrass and pearl millet both positively responded to increased N application rates. The highest yields were produced from the highest fertilizer rate which was 112 kg N per ha. The rationale for producing these summer annual grasses with no N fertilization would be to minimize inputs for biomass production. Low input management practices represent a more carbon neutral approach to producing these crops. However, to attain similar yields as the high input practice approximately double the land would be necessary. Harvesting sorghum-sudangrass and pearl millet at full maturity produced higher yields generally. Pearl millet plots during 2017 had poor stands directly following planting which led to slow and limited plant growth. This is one reason attributed to multiple harvest producing higher yields in this instance. Sorghum-sudangrass produced higher yields numerically opposed to pearl millet. Overall, harvesting sorghum-sudangrass at full maturity fertilized with 56-100 kg N per ha produced the highest yields for biomass fuel production.

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Appendix A

Complete results from biomass fuel pellets produced on-farm in 2016

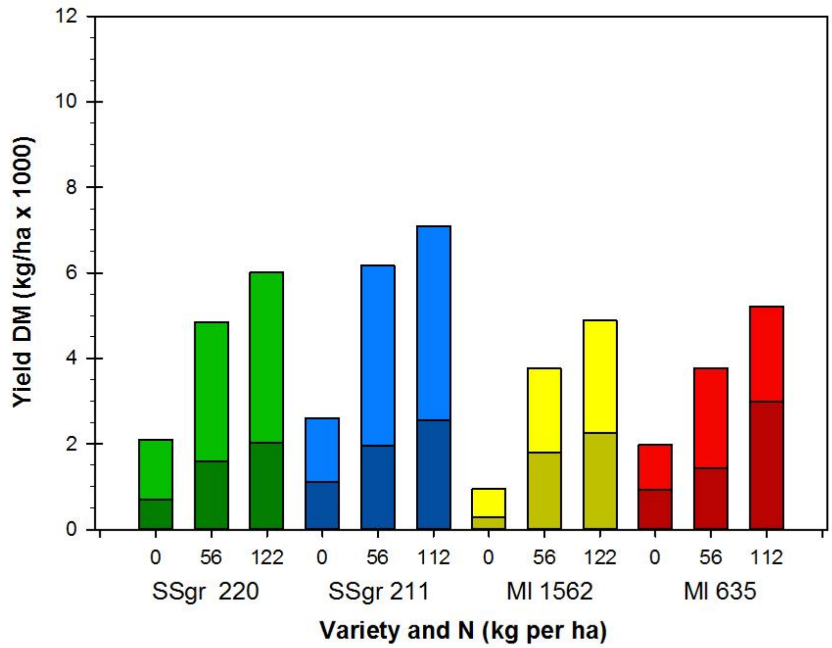
	Testing Criteria								
Biomass Pellet Sample	**Bulk Density lb/cu. Ft.**	**Diameter, in.**	**Pellet Durability Index**	**Fines, %**	**Inorganic Ash %**	**Length, %>1.50 in.**	**Moisture %**	**Chloride ppm**	**Heating Value, BTU**
Premium Wood Pellet Standards	**40-46**	**0.230-0.285**	**≥ 96.5**	**≤ 0.5**	**≤ 1**	**≤ 1**	**≤ 8**	**≤ 300**	**≥ 8000**
Season 2016 First Harvest									
Ml BMR	41.4	0.246	96.2	0.3	8.4	0	9.4	2752	7131
Ml NMBR	43.0	0.243	97.8	0.2	7.9	0	7.7	2422	7137
SSgr BMR	36.7	0.255	94.7	0.4	8.2	0	9.4	3025	7150
SSgr NBMR	33.7	0.253	93.7	0.2	6.9	0	9.9	2625	7151
Second Harvest									
Ml BMR	37.7	0.249	94.2	0.2	6.6	0	9.8	3774	7128
Ml NMBR	38.7	0.244	94.6	0.2	6.4	0	9.7	3435	7152
SSgr BMR	39.8	0.249	97.9	0.1	5.7	0	8.9	3064	7277
SSgr NBMR	42.6	0.245	98.2	0.3	5.0	0	7.9	2762	7353
Average Season 2016									
Ml BMR	39.5	0.248	95.2	0.2	7.5	0	9.6	3263	7129
Ml NMBR	40.9	0.244	94.6	0.2	6.4	0	9.7	3435	7152
SSgr BMR	39.8	0.249	97.9	0.1	5.7	0	8.9	3064	7277
SSgr NBMR	38.2	0.249	95.9	0.2	6.0	0	8.9	2693	7252

Appendix B

Complete results from biomass fuel pellets produced on-farm in 2017

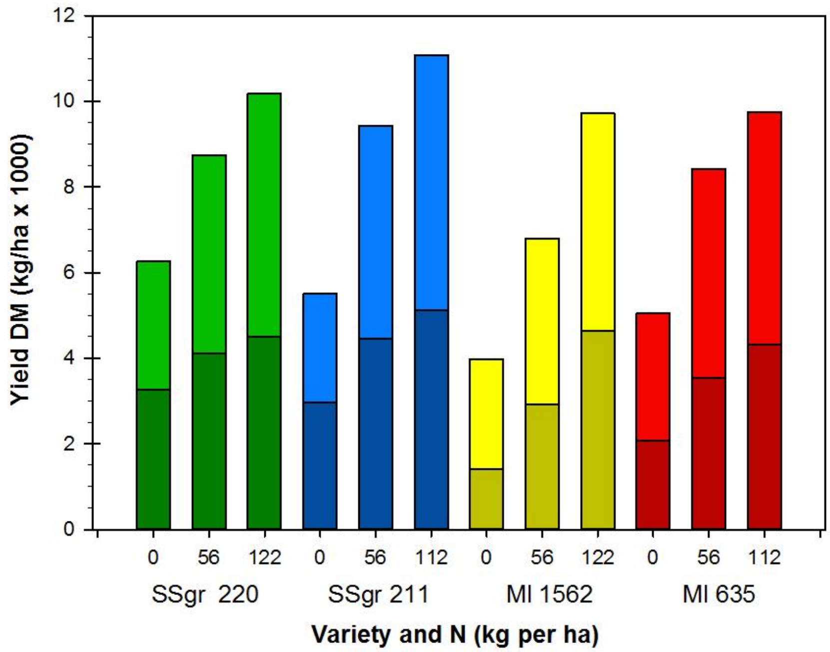
	Testing Criteria								
Biomass Pellet Sample	Bulk Density lb/cu. Ft.	Diameter in.	Pellet Durability Index	Fines %	Inorganic Ash %	Length %>1.50 in.	Moisture %	Chloride ppm	Heating Value BTU
Premium Wood Pellet Standards	**40–46**	**0.230-0.285**	**≥ 96.5**	**≤ 0.5**	**≤ 1**	**≤ 1**	**≤ 8**	**≤ 300**	**≥ 8000**
Season 2017 First Harvest									
Ml BMR	40.2	0.255	93.6	0.2	9.1	0	7.0	2422	7135
Ml NMBR	43.3	0.249	97.7	0.0	8.7	0	6.3	2086	7264
SSgr BMR	40.0	0.258	95.6	0.1	6.7	0	7.1	2047	7300
SSgr NBMR	36.9	0.273	91.6	1.8	6.2	0	6.9	1677	7431
Second Harvest									
Ml BMR	41.7	0.257	92.9	0.2	8.7	0	6.6	3024	7128
Ml NMBR	39.4	0.266	95.0	0.3	7.2	0	9.2	2794	7206
SSgr BMR	37.5	0.267	97.4	0.1	6.6	0	11.3	1778	7138
SSgr NBMR	41.1	0.251	95.9	0.1	6.2	0	6.5	1920	7548
Average Season 2017									
Ml BMR	41.0	0.256	93.3	0.2	8.9	0	6.8	2723	7131
Ml NMBR	41.3	0.257	96.3	0.1	8.0	0	7.7	2440	7235
SSgr BMR	38.8	0.262	96.5	0.1	6.7	0	9.2	1912	7219
SSgr NBMR	39.0	0.262	93.7	0.9	6.2	0	6.7	1799	749

Appendix C



Total yield of four pearl millet and sorghum-sudangrass varieties at 0, 56, and 112 kg per ha N in 2016. The yields at the first and second cuttings are shown as the lower and upper portions of each bar, respectively.

Appendix D



Total yield of four pearl millet and sorghum-sudangrass varieties 0, 56, 112 kg per ha N in 2017. The yields at the first and second cuttings are shown as the lower and upper portions of each bar, respectively.