



## In-field direct combustion fuel property changes of switchgrass harvested from summer to fall

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### ABSTRACT

Switchgrass, a perennial warm-season grass and potential energy crop, is usually harvested during the time between full maturity in the fall to the following spring. During this wide harvest window, the changes in fuel properties that could occur are important for making appropriate decisions with respect to the optimum harvest time for maximum fuel quality. A field plot study was carried out to investigate the quantitative fuel properties (proximate, ultimate and mineral analyses) of switchgrass over a harvest period from crop maturity in July through November. Harvest moisture decreased from July to November and moisture was uniformly distributed in the switchgrass plant at all times in the harvest period. There were significant differences in ash, volatiles, fixed carbon and nitrogen among months of harvest. Nitrogen, ash and fixed carbon contents decreased while oxygen and volatiles increased through the harvest period. Also, there were significant differences in oxides of silicon, calcium, potassium, phosphorus and sulfur among harvest times. The concentration of oxides of potassium and sulfur decreased at the end of the harvesting period. Fouling and slagging indices decreased as harvest was delayed but remained low throughout harvest. However, the decreases are small and might not dramatically impact fouling and slagging. Overall, the results appear to favor a later harvest for switchgrass used for direct combustion. This study will benefit feedstock producers as well as biomass feedstock facility operators by providing a better understanding of how the properties of switchgrass vary over a typical harvest period and their potential effect on boiler equipment.

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### 1. Introduction

Switchgrass (*Panicum virgatum*, L.), a perennial warm-season grass, is desirable as a potential biofuel in direct combustion systems because of its excellent burn quality, ease of management, and high yield. During the harvest period, the quality and quantity of switchgrass, as well as other herbaceous perennials, change over time. In summer harvest, when the plant is mature, there will be higher yields as opposed to late fall and early winter harvest when dry matter losses can occur due to plant lodging and biodegradation over time. However, switchgrass harvested in the summer is wet and requires that the cut plant be left in windrows to dry before baling. This poses some risk from inclement weather compared to switchgrass harvested in the fall when the plant would have dried to safe baling moisture and thus might not require the cut plant to field dry prior to baling. High moisture feedstock is difficult to manage and reduces the heat available from the fuel during direct combustion by lowering the initial gross

calorific value of biomass. Fuel moisture reduces the combustion efficiency since heat is absorbed in evaporation of water in the initial stages of combustion which lowers the flame temperature as well [1].

The prediction of combustion for the purposes of design and control requires knowledge of fuel properties and the manner in which these properties influence the combustion process [2]. A problem that switchgrass and other herbaceous energy crops pose during combustion is the amount of ash in the biomass material. Ash is the inorganic residue remaining after ignition of herbaceous biomass. It influences the performance of combustion equipment and is composed of alkali minerals containing silicon (Si), aluminum (Al), calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K). Jenkins et al. [2] stated that alkali and alkaline earth metals, in combustion with other elements such as silica and sulfur, and facilitated by the presence of chlorine (Cl) are responsible for many undesirable reactions in combustion furnaces and power boilers. Ash components of major concern are Na, K, Cl, S (sulphur), Zn (zinc), and Pb (lead) because about 80% are evaporated during combustion while only about 20–50% of other inorganics such as Ca, Mg, Mn (manganese), P (phosphorus) and Ti (titanium) are released [3]. Miles et al. [4] stated that potassium is often organically bound in biomass which will vaporize and decompose during combustion and will form oxides,

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hydroxides, chlorides and sulfates which react to form low-melting point species such as potassium silicate which condense on boiler walls, tubes and fly-ash particles causing slagging and fouling.

Agricultural crop studies have included implementing a very late season harvest, delayed to after frost to permit retranslocation of nutrients such as K, P and N below ground. Both retranslocation and leaching from senescent foliage contribute to lowering nutrient levels. Parrish et al. [5] stated that biomass harvested in late fall through early spring provides a higher quality fuel with less ash content than that of summer. The harvest of reed canary grass (*Phalaris arundinacea* L.), a herbaceous biomass crop, for combustion was evaluated by Hadders and Olsson [1]. It was determined that the composition of agricultural crops harvested in the summer is generally not very suitable for combustion because of the high contents of ash, nitrogen, potassium and chlorine. Harper [6] added that there are trade-offs in delaying harvest even as late as the following spring. While biomass yield decreases over the winter, mineral and moisture contents decrease as well, which both positively affect the feedstock value from a combustion stand point. Therefore, timing switchgrass harvest two to three weeks after a killing frost through March is desirable.

Due to the composition of minerals in biomass, deposition of the ash occurs when the fuel is mixed intimately with hot air and burned at high temperatures. Part of the ash is deposited on boiler surfaces, producing slagging and fouling in certain areas of the boiler. Skrifvars [7] stated that the accumulation of extensive ash deposits on radiant or convective heat transfer surfaces would lead to higher gas temperatures, damage to pressure parts in the lower area of the furnace and an increase in draft loss increasing static pressure losses and reducing steam output. A running slag is produced along the walls of the boiler as a result of alkali metals reacting with particles of fly ash. The flow characteristics of the generated slag depend on its viscosity. Arvelakis et al. [8] stated that in systems that must maintain a slag flow, the temperatures of the slag must be high enough to produce a low-viscosity slag that will flow ( $T_{250}$ ); the temperature in which the slag viscosity is 250 poises. Unequivocally predicting the slagging and fouling properties of a given fuel would seem unattainable. However, predicting ash fusibility has been achieved using correlations between fusion temperatures and standardized chemical composition of ashes in a base-to-acid ratio (B/A) which were developed for coal samples. The basic (base) constituents are Fe, the alkaline earth metals Ca and Mg, and the alkali metals Na and K. The acidic (acid) constituents are Si, Al and Ti. Pronobis [9] stated that so-called basic compounds lower the melting temperatures, while acidic ones increase it.

The results of the elemental ash analysis provides data used in calculating fouling and slagging indices via correlations. Gray and Moore [10] recommended using results of the elemental ash analysis to calculate the property of fouling. According to Pronobis [9], the base-to-acid ratio (weight %) in the biomass ash is a procedure for calculating furnace slagging. Furthermore, fouling and slagging potential can be utilized by boiler furnace and superheater designers. With knowledge of ash analysis of switchgrass alone or along with coal, designers can determine the number of wall blowers needed to control slag accumulation in plastic zones and superheaters which can be designed to permit control of ash deposits to avoid fouling/slagging problems. Reducing such problems during combustion of biomass will lead to increased boiler-performance efficiency while reducing operational costs.

In general, biomass components include cellulose, hemicelluloses, lignin, lipids, proteins, simple sugars, starches, water, HC, ash, and other compounds [11]. As was noted previously, these components determine the fuel properties. The concentrations of these components in a particular biomass species depend on the type of plant tissue, stage of growth, and growing conditions (environment, soil type, cultural practices, etc.) [11]. Therefore, it might be important to understand how some of these factors affect biomass fuel properties and evaluate the relevance of their inclusion when reporting fuel prop-

erties. This study investigated the in-field combustion fuel properties of switchgrass harvested from maturity in the summer through fall (July to November). The fuel analyses conducted included proximate, ultimate and mineral analyses. Additionally, the moisture content of three sectioned parts of switchgrass stem was monitored from summer to fall harvest to investigate the uniformity of moisture distribution in the plant during the harvest period. In addition, we examined the implications of harvest time decisions in regard to fuel properties as they affect boiler performance using base-to-acid (B/A) ratio, fouling and slagging indices,  $T_{250}$ , silica value and percent alkali as  $\text{Na}_2\text{O}$ .

## 2. Materials and methods

### 2.1. Sample collection

Switchgrass (variety not stated) which was used in this study was seeded in 1987 and grown in a small plot approximately 20.9 m<sup>2</sup> (225 ft<sup>2</sup>) at the Purdue Agronomy Center for Research and Education (ACRE) in West Lafayette, Indiana. Burning of the previous year's residue occurred in late April and nitrogen fertilizer was applied at a rate of 56 kg/ha. The switchgrass plot (Fig. 1) was randomly sectioned in June, 2006 into twelve 1.115 m<sup>2</sup> (12 ft<sup>2</sup>) pre-assigned sub-plots representing three replications for the months of July, August, October and November. To allow time for recovery following harvest, switchgrass was not collected between September 5 and October 20. Three samples were collected monthly from their respective sub-plot within an area of 0.3716 m<sup>2</sup> (4 ft<sup>2</sup>) using a 0.61 m<sup>2</sup> (2 ft<sup>2</sup>) wooden constructed square grid to determine the yield (Mg/ha). Shears were used for cutting, leaving about 15 cm of stubble to provide shoot buds/protection for regrowth. At harvest, each switchgrass plant was separated into three 0.15 m (6 inch) sections (bottom, middle and top), tested for moisture content immediately after harvesting using ASAE S358.2 (25 gram samples were cut to small pieces to fit the sample cup and dried at 103 °C for 24 h) [12]. After harvest, samples were stored for future fuel analyses (proximate, ultimate and mineral) in a storage cooler located in a Purdue University lab at −18 °C (0 °F) to retain initial chemical properties.

### 2.2. Fuel analysis

After the final harvest in November, 12 samples (4 months, 3 replicates) were collectively sent to Standard Laboratories Inc. (Evansville, Indiana) for proximate, ultimate and mineral analyses using ASTM D3176-89 [13]. Proximate analysis provided percentage values for moisture content, volatile content (when heated to 950 °C), the free carbon remaining at that point, the ash (mineral) in the sample and the energy content of switchgrass on a dry basis. Ultimate analysis provided the composition of the biomass in percent weight of the major components carbon, hydrogen, nitrogen, oxygen and sulfur. Mineral



Fig. 1. Diagram of switchgrass plot with randomly chosen sub-plots labeled with the months of harvest.

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