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STRATEGIES TO REDUCE THE ASH CONTENT IN PERENNIAL GRASSES

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ABSTRACT

Perennial grasses have been identified as the lowest cost dedicated agricultural feedstock for energy and agri-fibre markets. However, it is of paramount importance that the ash content of these feedstocks be reduced so as to facilitate their commercialization. High ash contents are particularly troublesome for achieving efficient combustion when used for bioenergy applications, and in chemical recovery systems, in the pulp and paper industry.

The major component of ash is silica. Warm season (C_4) grasses are found to have lower silica levels than C_3 grasses owing primarily to the fact that they utilize water 50% more efficiently. Silica levels in grasses are also highly influenced by the monosilicic acid content of soils. As a result, clay soils produce higher silica containing feedstocks than sandy soils. Silica levels are lowest in the stem fraction of grasses, and highest in inflorescences, leaves, and leaf sheaths. Selection for higher stem content will help to reduce the plant's ash content, while increasing the desirable feedstock characteristics, such as cellulose content, which is important for ethanol and pulp and paper markets.

Reducing the potassium and chlorine contents of feedstocks grown for fuel purposes is important to improve combustion efficiencies. The chlorine content of feedstocks is strongly influenced by fertilization practices and can be minimized by using chlorine free fertilizers. Potassium and chlorine contents can be reduced to similar levels as wood chips by overwintering the grasses, however, there is a trade off in that lower yields are harvested. The feedstock production cost of overwintered switchgrass is lower than short rotation forestry, and switchgrass provides similar properties for combustion as wood.

Keywords: ***biomass combustion, ash, silica, perennial grass biofuels, switchgrass.***

INTRODUCTION

Much success has been achieved in reducing biomass energy feedstock costs over the past ten years in North America. The perennial grass switchgrass has been found to reduce dedicated energy feedstock costs by 30-40% on an equivalent yield basis with short rotation forestry (Girouard et al., 1995). Crop residues are generally less expensive to grow as biomass energy feedstocks, but have biomass quality deficiencies which restrict their use in bioenergy conversion systems.

The major obstacle in using herbaceous biomass material for heat and electricity generation, is their unsuitability as efficient combustion material compared to wood. High silica, potassium and chlorine contents of herbaceous feedstocks can combine to cause fouling and slagging of combustion systems when temperatures exceed the melting point of ash. Herbaceous biomass feedstocks can only begin to competitively displace fossil fuels once they are used in modern energy efficient end use technologies. Therefore, the use of herbaceous feedstocks for heat and electricity applications necessitates that combustion efficiency problems with higher ash fuels be overcome.

A definitive mean of overcoming this obstacle is to work on improving combustion systems designed to handle higher ash fuels, as well as to develop feedstocks with improved biomass quality. On the combustion technology side, breakthroughs have already been made with the recent development of the Delpoint Gasifier pellet stove (SERBEP, 1998) which is capable of burning higher ash containing agricultural fuels. Nevertheless, lowering the ash content of feedstocks remains a desirable goal as it results in lower rates of equipment wear and maintenance, less ash removal, and ultimately lower fertilization requirements for feedstock production. As well, developing low ash content feedstocks may be important in finding higher value markets. Wood pellets currently retail for US $120/tonne in Canada. The development of low ash agricultural feedstock (<3% ash) could significantly expand the biofuel market, especially with the development of the new gasifier pellet stove. Switchgrass has already been extensively evaluated as a feedstock for the pulp and paper industry and no technical barriers block its commercialization (Girouard and Samson, 1998; Radiotis et al., 1996). However, reducing the silica levels in switchgrass would enable it to be used in higher level blends with wood fibre in paper manufacturing, thereby simplifying the chemical recovery process in the pulp and paper mills.

This paper will review agronomic strategies to reduce the ash content of feedstocks, focusing on silica and potassium levels, with emphasis on comparing switchgrass to other perennial grasses.

Silica

The ash component of plants varies greatly between families of plants as well as between individual species. The largest mineral component of ash, in perennial grasses, is silica.

There are two principle ways in which silica comes into contact with biomass feedstocks; i) through surface deposition by soil contamination and ii) internally through water uptake by passive water flow and/or metabolic processes. In perennial grasses the major mechanism of silica entry is through the uptake Of silicic acid in water. Crop residues, such as corn and straw, are generally higher in silica levels than dedicated feedstocks as these residues are more exposed to wind erosion during the production cycle, and to soil contamination during harvesting.

The main difference in silica contents between perennial grass species is often related to the photosynthetic mechanism of the grass, and to the amount of water being transpired by the plant. Warm season (C_4) grasses, on average, use half as much water as C_3 grasses per tonne of biomass produced (Black, 1971). The decreased water usage reduces the uptake of silicic acid and decreases the ash content of the plant. This effect was demonstrated in an analysis of various feedstocks collected by REAP-Canada for analysis by the pulp and paper industry (Table 1). The C_3 species (reed canary grass and phragmites) were found to have more than twice as much % ash content as the C4 species (prairie cordgrass, switchgrass, big bluestem, prairie sandreed, and miscanthus). Wheat straw was found to have a higher ash content than other C_3 species because it was also grown on a clay soil (to be discussed), and the residue is prone to silica deposition during the production and harvesting processes.

Table 1. Ash Content of Wheat Straw and Overwintered Perennial Grasses

Prairie cordgrass *(Spartina pectinata)*	C4 perennial	1.6
Switchgrass *(Panicum virgatum)*	C4 perennial	1.7
Big bluestem *(Andropogon gerardii)*	C4 perennial	1.8
Prairie sandreed *(Calamovilfa longifolia)*	C4 perennial	1.9
Miscanthus *(Miscanthus sinensis)*	C4 perennial	2.0
Reed canarygrass *(Phalaris arundinacea)*	C3 perennial	6.3
Phragmites *(Phragmites communis)*	C3 perennial	7.5
Wheat straw	C3 annual	11.1

Adapted from Radiotis et al., 1996

Within species, the water use efficiency will fluctuate depending on the region in which the crops are grown, and on the soil type. Water use per tonne of biomass produced is highest in regions which have a low rainfall to evaporation ratio, and where biomass crops are grown on marginal soils (Samson et al., 1993; Samson and Chen, 1995). A combination of these conditions may explain some of the higher values obtained by a US survey reporting switchgrass ash contents of 2.8%-7.6% (McGlaughlin et al., 1996).

The translocation and deposition of silica in plants is also heavily influenced by the soluble silica levels in the soil, which is present as monosilicic acid; Si(OH)4 (Jones and Handreck, 1967). Clay soils have higher monosilicic acid levels than sandy soils, and therefore produce feedstocks with higher silica levels. A Scandinavian study found silica levels in reed canarygrass to be highly influenced by soil type; reed canarygrass had silica levels of 1.3%, 1.9% and 4.9% on sandy, organic, and clay soils, respectively (Pahkala et al., 1996). In Denmark, high silica contents in wheat straw were strongly correlated to clay soils as well (Sander, 1997).

Silica is mainly deposited in the leaves, leaf sheaths and inflorescences of plants (Lanning and Eleuterius, 1989). Lanning and Eleuterius (1987) found switchgrass silica contents to be 1.03%, 3.85%, 3.41% and 5.04% in stems, leaf sheaths, leaf blades and inflorescences, respectively, in Kansas prairie stands. Silica levels are suggested to have evolved to be high in inflorescence structures to prevent the grazing of seed heads (Lanning and Eleuterius, 1987). In contrast, the stem fraction of grasses was found to contain the lowest silica levels. Due to the low stem silica content, the overall silica concentration of the grass decreases as the stem content increases. Pahkala et al. (1996) examined 9 different varieties of reed canarygrass and found varieties to range from 2.3% to 3.2% silica content, the lower silica containing varieties had a higher biomass stem fraction. Thus, selection for stem content is desirable for improving the biomass quality for combustion purposes, given lower silica levels. As well, grass cellulose content was found to be highest in the stem fraction (Radiotis et al., 1996), increasing the stem content could increase the value of the material for cellulosic ethanol, and pulp and paper markets.

Silica in monocotyledons has a functional role which has been most extensively studied in sugar cane and rice, where it has been identified to provide several important functions, including providing mechanical strength (Majumder et al., 1985), improving phosphorus uptake, and disease and pest resistance (Jones, 1985). Less clear is the importance of silica in monocotyledons in temperate regions. Interestingly, in livestock production, silica has been found to cause kidney stone formation and to cause excessive wear on sheep teeth (Salisbury and Ross, 1978). Thus, problems with high grass silica contents are not confined to combustion systems alone!

Other Inorganic Components of Grasses

The high potassium and chlorine contents of grasses need to be addressed to facilitate their combustion efficiency. For example, wood chips typically have a potassium content of 0. 1% and a chlorine content of 0.02% (Sander, 1997). Switchgrass has been reported to have a late summer-early fall harvested potassium content of approximately 0.7-1.0% (Radiotis et al., 1996; Sanderson and Wolf, 1995) and a chlorine content of 0.46%

(Dayton and Evans, 1997). For power generation in Denmark, Sander (1997) found straw samples to greatly exceed the target values of 0.2% potassium and 0. 1% chlorine for biomass feedstocks. Subsequent field research found chlorine contents to be strongly correlated to potassium chloride fertilizer usage. Both the use of chlorine free fertilizers, as well as delaying field harvest to allow chlorine to be leached out of the grass by the rain, were found to rectify the problem (Sander, 1997).

Warm season prairie grasses, such as switchgrass, have low potassium contents compared to C_3 grasses (Smith and Greenfield, 1979). The low inherent potassium requirements of the grasses combined with their extensive root network which is able to tap into areas of higher nutrients, are responsible for the relatively low response to potassium fertilization observed in research trials. During the growing season the potassium content declines curvilinearly as the plant matures (Sanderson and Wolf, 1995). However, the potassium content of the material in the fall remains about 5 times that of the aforementioned Danish target level for power generation.

Fortunately, the potassium component of the crop can be manipulated as it is highly water-soluble. Prairie ecology studies indicate potassium in unharvested material to be effectively recycled into the soil over the late fall and winter (Koelling and Kucera, 1965; White, 1973). Overwintered big bluestem residues were found to contain only 0.06% potassium in the spring (Koelling and Kucera, 1965). Analysis of overwintered switchgrass in southwestern Quebec indicated potassium levels to decrease from 0.95% in the fall to 0.06% in the spring (Radiotis et al., 1996) (Table 2). Overwintering switchgrass therefore, eliminates the need to apply potassium fertilizer and provides a feedstock with nutrient characteristics similar to wood chips. From Table 2, the nitrogen content of the overwintered feedstock was also reduced, which minimizes spring fertilization requirements, and nitrous oxide emissions into the atmosphere.

Table 2: Characteristics of Various Biofuel Feedstocks

Element	Wood Chips	Wheat Straw	Switchgrass (fall harvest)	Switchgrass (spring harvest)
Potassium (%)	0.1	1.0	0.95	0.06
Nitrogen (%)	0.3	0.7	0.46	0.33

Adapted from Radiotis, 1996; and Sander, 1997

Overwintering switchgrass, however, reduces the biomass yield obtained. Spring harvested switchgrass yields were found to be approximately 24% lower in southwestern Quebec than that of fall harvested switchgrass (Radiotis et al., 1996). This was due to both the late season translocation of materials to the root system in winter (Parrish and

Wolf, 1992), as well as the physical loss of leaves and seed heads during winter (Radiotis et al., 1996). The feedstock cost of the spring-harvested switchgrass (US $37 odMg) was found to be 17% higher than the base case value for fall harvested switchgrass (US $32 odMg). However, the spring harvested switchgrass was also found to be 19% less expensive to grow than the base case value for short rotation forestry willow, at US $46 odMg (Girouard et al., 1998).

Selecting less brittle switchgrass varieties and plants with higher stem to leaf ratios will improve the economics of spring harvesting. However, long term fall harvesting of switchgrass in more northerly regions requires further field testing to evaluate yield sustainability. With additional research in plant breeding, reducing yield and cost differences between fall and spring harvested material is achievable.

SUMMARY AND CONCLUSION

Perennial grasses are promising low cost dedicated biomass energy feedstocks that can be grown throughout the agricultural regions of North America. However, their use in heat and electricity generation has progressed slowly due to the high silica, potassium and chlorine contents of the feedstocks, which interfere with efficient combustion. Both biomass cost and quality must to be considered when developing bioenergy feedstock production systems. The ash content of grasses can be affected by many factors including choice of species and variety, choice of soil type and location, fertilization practices, and time of harvest. Overwintering switchgrass in northern regions can produce a feedstock with similar potassium and chlorine contents as wood chips while reducing feedstock costs by 19% compared to short rotation forestry. Plant breeding to increase the stem fraction of grasses may be helpful in reducing ash levels and improving other quality traits. Once better knowledge of factors influencing ash content of feedstocks is incorporated into biomass feedstock research and development, and combined with improvements in combustion technology, herbaceous biomass crops have an excellent opportunity to emerge as a major supply option for renewable energy.

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Home Page