Sustainability Protocols and Certification Criteria for Switchgrass-Based Bioenergy

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Production of bioenergy from cellulosic sources is likely to increase due to mandates, tax incentives, and subsidies. However, unchecked growth in the bioenergy industry has the potential to adversely influence land use, biodiversity, greenhouse gas (GHG) emissions, and water resources. It may have unintended environmental and socioeconomic consequences. Against this backdrop, it is important to develop standards and protocols that ensure sustainable bioenergy production, promote the benefits of biofuels, and avoid or minimize potential adverse outcomes. This paper highlights agronomic information on switchgrass, a high-potential bioenergy feedstock, and the role of specialized certification programs. The existing sustainability standards and protocols were reviewed in order to identify key gaps that justify a certification program specifically for switchgrass-based bioenergy. The criteria and indicators that should be considered for such a certification program are outlined.

Keywords: Bioenergy; Certification; Sustainability; Protocols; Indicators; Switchgrass

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INTRODUCTION

Among alternative energy sources, biofuels such as switchgrass-based ethanol have emerged as a favored option because they can address prevailing concerns about fossil fuel use and the belief that the transition will be relatively easy from a technological and infrastructure perspective. In addition, sizeable biomass yield and high carbohydrate content indicate that biofuels produced from switchgrass can compete favorably against other feedstocks from an economic perspective (McLaughlin and Kszos 2005; Daystar *et al.* 2013). Although US petroleum imports in 2014 were at their lowest level in approximately three decades, they fulfilled 27% of the country's petroleum needs (EIA 2015). Thus, the production of biofuels has the potential to enhance a country's energy security by limiting petroleum imports while supporting domestic agricultural markets, boosting industrial activity, and possibly reducing environmental impacts through greenhouse gas (GHG) reductions, when undertaken responsibly. Federal policies, including the 2005 Energy Policy Act and the 2007 Energy Independence Security Act (EISA), have encouraged the production of cellulosic biofuels, *i.e.*, fuels produced from energy grasses such as switchgrass and other woody biomaterials.

The United States ranked first in terms of annual investment and net capacity additions for biofuel production for both biodiesel and fuel ethanol in 2015 (REN21 2016). While biofuel production is likely to increase due to production mandates, tax incentives, and subsidies, if not implemented with care it could also cause some undesirable impacts.

Studies have highlighted the potential adverse impacts of bioenergy production in several areas, including land use and biodiversity (Firbank 2008), GHG emissions (Searchinger *et al*. 2008), socio-economic ramifications (German *et al*. 2011), and the availability of water resources (Berndes 2002). It is important to ensure that opportunities for new activities in the field of bioresources do not come at the cost of nature, the environment, and society (Cramer 2007). Accordingly, it is crucial to consider the environmental, social and economic impacts of promoting biofuel production and consumption along the entire supply chain, ranging from production of raw materials to its intended use as a fuel.

A potential approach to ensure sustainable biofuel production is the establishment of certification criteria (Hunt and Forster 2006). This research highlights production and agronomic information on switchgrass use in bioenergy production, the role of certification programs, a review of existing programs, the identification of key gaps that justify a specialized certification program, and potential criteria and indicators that may be considered. We use the case of switchgrass to highlight important components of a robust certification program and develop a template that can be adapted for other bioenergy feedstocks. The first section highlights the agronomy of switchgrass, its ecological services, and its potential as a biofuel feedstock. The next section presents an analysis of conventional biomass production and marketing certification programs. Potential gaps that underscore the need for specialized sustainability criteria and indicators for switchgrass are identified and followed by a description of the opportunities presented by such a certification program. The subsequent section presents criteria and indicators for a switchgrass-based biofuel certification program. The final section addresses the future research and outreach needs for increased use of switchgrass as a bioenergy feedstock and the implementation of a certification program.

Why Switchgrass-based Bioenergy?

Switchgrass (*Panicum virgatum*) is a perennial high-fiber grass, native to the tall-grass prairie of the U.S., except for California and the Pacific Northwest region (Vogel *et al.* 2004). It grows in a wide range of agronomic conditions, including dry and poorly drained soils, shallow and dry soils, as well as shores, riverbanks, marshes, and oak and pine woodlands. It can grow in various soil types and in soils with pH levels ranging from 4.5 to 7.6 and with little to no fertilizer application (Hanson and Johnson 2005; Rinehart 2006). While switchgrass does not require much water (Casler *et al.* 2004), it also is highly resistant to pests and diseases (Vogel *et al.* 2004). It can grow in areas susceptible to flooding, facilitate habitat protection, and create winter wildlife cover and nesting areas (Wright 2007; Liebig *et al.* 2005; Varvel *et al*. 2008). The deep root system also provides other ecosystem services, such as greater soil organic carbon storage in underground biomass at greater depth, rather than near the surface where it is susceptible to mineralization and loss (Frank *et al.* 2004; Liebig *et al.* 2005; Lee *et al.* 2007). Switchgrass also reduces surface water velocity and enhances infiltration. It can also serve as a windbreak for field crops, as well as mitigate run-off from agricultural fields (Liebig *et al.* 2005).

Currently, switchgrass is cultivated in the US for pasture and hay to feed livestock (McLaughlin *et al.* 2005). The US Department of Energy identified switchgrass as a high potential energy grass because of its adaptability and yield potentials (Wright 2007). Switchgrass does not have the annual establishment and fertilization needs of corn, soybean, and other crops that have been considered for biofuel production. Switchgrass increases the amount of organic matter in the soil, while reducing soil carbon release associated with annual site establishment. This reduces the cost associated with purchase, transport, and management of seedlings, while enhancing net energy performance, which could result in a better overall GHG performance (Tilman *et al.* 2006; Vadas *et al.* 2008; Varvel *et al.* 2008). With minimal boiler retrofitting needs, switchgrass can be co-fired with coal in thermal plants (Mitchell *et al.* 2012). Moreover, the limited need for specialized equipment, especially for on-farm activities ranging from cultivation to harvest, to manage switchgrass cultivation does not impose additional costs and enhances its overall economic viability.

Switchgrass plantations can produce as much as 16 tons of dry biomass per acre under good management in the wetter southeastern regions. Comparatively, the drier Northern plains have a different cultivar with lower yields. Roughly 80 gallons of ethanol can be produced per dry ton of feedstock (Mitchell *et al.* 2012). Additional benefits of using switchgrass as a biofuel feedstock include avoiding the food/fuel controversy, not competing for prime agricultural land and making use of otherwise unusable land while restoring its quality for other uses (Sanderson *et al.* 1996). Potentially, switchgrass-based bioenergy can add to the broader socioeconomic and environmental benefits associated with a growing bioenergy sector. Benefits include the diversification of feedstock portfolio and supplemental income to landowners, creation of local jobs and tax revenue that revitalizes rural economics, the ability to meet growing energy services demand at lower environmental costs, and a reduction in the dependence on petroleum imports for energy supply.

METHODS

Analysis of Existing Frameworks

There are numerous certification programs for agriculture, forest output, and biomass that are currently being implemented or developed. These programs include the American Tree Farm System, Basic Criteria for Responsible Soy Production, Protocol for Fresh Fruit and Vegetables, Program for the Endorsement of Forest Certification, International Sustainability and Carbon Certifications (ISCC), Global Bio-Pact, Ethical Trading Initiative, Fair Trade Labeling Organizations International, Flower Labeling Program, Forest Stewardship Council (FSC), Green Gold Label, International Federation of Organic Agriculture Movement, Principles and Criteria for Sustainable Palm Oil Production, Sustainable Agricultural Standards, Sustainable Forestry Initiative, and Roundtable on Sustainable Biofuels (RSB), *etc*. These certification programs feature common sustainability criteria, such as biodiversity, agrochemical application, and the impact on soil and water. Despite these similarities, they also exhibit differences in the number, depth, and type of criteria involved, which highlight differentiated priorities. While these impact categories represent the main drivers and concerns in the current certification efforts, there are several additional performance-related criteria and indicators, including GHG emissions and air pollution performance, which require more attention.

Meanwhile, enhanced computing capacity allows for the evaluation of large collections of reports, peer-reviewed journal articles, working papers, *etc*., using text analysis and text visualization tools. Text mining borrows techniques from several fields, including linguistics, computational statistics, and computer science (Meyer *et al.* 2008). Word clouds and word frequency charts depict representative keywords contained in a set of documents being studied or analyzed (Cui *et al.* 2010). Apart from providing a visual representation, frequency charts and word clouds also demonstrate key ideas and important themes contained within published literature.

In this paper, a text analysis was performed using the computing software R (Williams 2016) on important standards and certification guidelines such as the RSB, FSC, ISCC, as well as reports published by the Council on Sustainable Biomass Production (CSBP), Biomass Technology Group, and the group on Sustainable Production of Biomass. In addition, academic literature, including the papers by Lewandowski and Faaij (2006), Van Dam *et al.* (2008), Lee *et al.* (2008), Lal *et al.* (2011), the 2013 discussion paper by Annalisa Zezza on Sustainability Certification in the Biofuel Sector, and the working paper by Devereaux and Lee (2009) were analyzed. The text mining algorithm uses a procedure called Stemming, which removes common word endings such as 's,' 'es,' 'ed,' *etc*. (Williams 2016). In Fig. 1, there is a word cloud that provides a visual of the 100 most frequently used words in the papers previously listed. Figure 2 depicts the absolute frequency of the words that appear more than 400 times in these papers and documents. The frequencies of the words will likely increase with the number of papers included in the analysis. This analysis and visual representation provides insights about some of the major focus areas for certification criteria and production standards that have been published previously. While the text analysis highlights important key-words and is useful for illustrative purposes, the text analysis and word cloud was followed by in-depth review of existing standards and certification criteria.

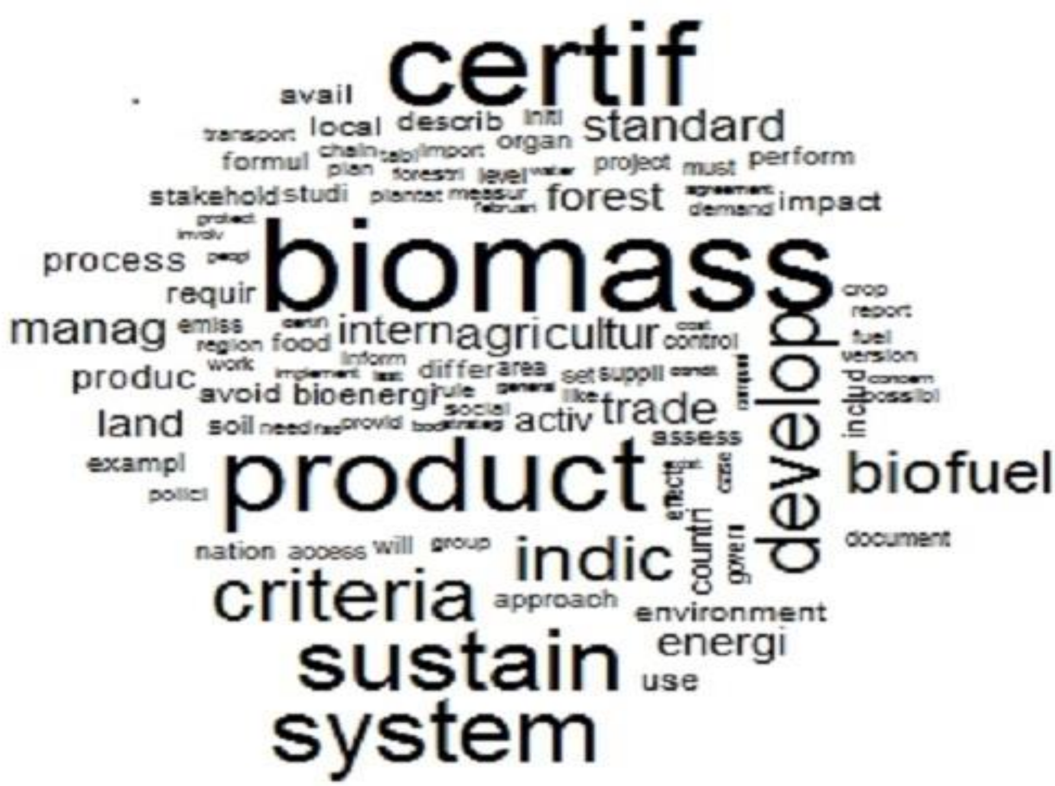

Fig. 1. Word cloud representing the 100 most-frequent words in the text analysis

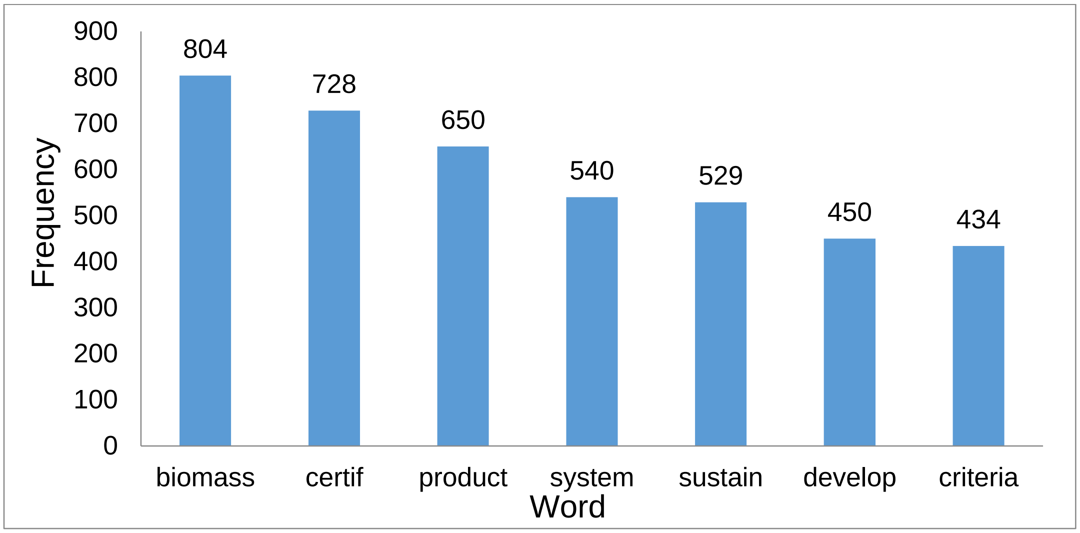

Fig. 2. Words appearing more than 400 times in the cumulative text analysis

Table 1A. Snapshot of Different Certification Programs on Select Criteria to Highlight the Range of Coverage and Specificity

	Roundtable on Sustain-able Biomaterials (RSB)	Renewable Energy Initiative (RED)	Renewable Fuel Standard Program (RFS2)
Greenhouse Gas Emissions	On average 50% savings compared to fossil fuel baseline, and progressive improvements over time	35% savings for all biofuels progressing to 50% and 60% by 1 Jan 2017 and 1 Jan 2018 respectively	Different savings criteria based on biofuel category: Cellulosic ethanol: 60% Biomass-based diesel: 50% Renewable Fuel: 20%
Land Use change	Multiple criteria ranging from consent of local communities, food security impacts, impact on endangered species, property rights, *etc*.	Restrictions on conversion of highly biodiverse lands, high carbon stock lands, and peatlands	Planted crops/trees and residues restricted to lands cleared/cultivated prior to December 2007
Soil and Water	Guidelines aimed at enhancing/maintaining physical, chemical, and biological properties of soil as well as quality and quantity of surface and ground water	No specific guidelines; Member states that are significant source of biofuels or raw materials must report national measures	No specific guidelines, however, impacts to date and likely future impacts to be assessed and reported every 3 years
Sources: RSB (2013); Alberici *et al.* (2014)			

Biomass certification programs exhibit differences in terms of generalizability, end use specificity, and applicability across the supply chain. They also differ in terms of the chains of custody they operate; different versions including fully segregated through the supply chain or mass balance with percentage of approved raw material use indicated in the final product. Differences also exist in the advancement of the certification efforts for different energy crops, including those that have reached advanced stages (Round Table on Sustainable Palm Oil), those that are in progress (Round Table on Sustainable Soy and Better Sugarcane Initiative), to those that have yet to be initiated (wheat, sugar beet, switchgrass, and rapeseed) (Vis *et al*. 2008).

Table 1B. Criteria, Guidelines, and Indicators for Land Use and Competition with Food Crops

Criteria and Guidelines
1.1 Minimize conversion of potentially fertile land to growing switchgrass or setting up conversion/processing facilities. 1.2 Ensure that diversion of land to a switchgrass dedicated farm does not infringe on food production and lead to propagation of monocultures. 1.3 Biomass production should not result in irrecoverable losses to above ground vegetation or carbon sinks and should be supported with documentation showing a positive net benefit from reduced material and energy use over the lost opportunity of using the land for other productive uses. 1.4 Biomass production should not result in a substantial loss of soil carbon; for example peatland, wetland, and mangrove cultivation. 1.5 The practice of growing switchgrass for bioenergy should adhere to socially established agronomic and operational norms of agricultural production and avoid competing local community out of the land market.
Indicators
1.1 Net GHG emission change comparing previous land use to current use. 1.2 Documentation of changes to land use patterns and information of overall crop mix. 1.3 Documentation of changes to local/regional land prices and comparison with past trends. 1.4 Documentation of changes to local/regional food output and prices, and comparison with past trends.
Sources: Rinehart 2006; Casler *et al.* 2007; Cramer *et al*. 2007; Mitchell *et al.* 2008; Varvel *et al.* 2008; Vogel *et al.* 2008; Mitchell *et al.* 2012; NRDC 2014.

Standards and certification measures can evaluate various aspects of biomass production. There is a lot of variety in the main objectives they pursue, such as ensuring safety, establishing liability, or differentiating products. Additionally, they can measure the extent of the burden and benefit conferred on different applicants, such as small-scale farmers compared to large-scale incorporated farms. Certifications vary in the number, type, and detail of criteria given; the type of biomass production system (forest, energy crop, power sector, emissions trading) (Vis *et al.* 2008); regional scope (international as in the Forest Stewardship Council, or country/regional as in the Sustainable Forest Initiative) (Cramer *et al.* 2007); breadth of the structure (umbrella structure or national systems); hectares of land currently covered by the certification program; and the scope of their efforts, such as a stand-alone certification, such as the International Sustainability and Carbon Certifications, or the development and harmonization of different biomass production system certification protocols as in the Global Bio-Pact (Ladanai and Vinterbäck 2010).

Need for a Specialized Certification Program for Switchgrass-Based Biofuels

Development of feedstock specific standards and protocols provides a potential pathway to maximize the advantages of a certification program. While some standards and criteria from existing programs can be incorporated, such as those for feedstock cultivation and management, energy balances, GHG emission reductions, biomass harvesting, transport and conversion, the opportunity to account for specific requirements of different feedstock can result in substantial gains. New and specialized certification protocols could be important additions to generic biomass certification protocols by creating new criteria and indicators, broadening the base of biomass production covered, and ensuring the sustainable production and marketing of biomass. In addition to meeting long-term sustainability objectives through the implementation of sustainability criteria and indicators through a certification program, growers may benefit from charging premiums, building consumer confidence, and communicating the responsible sourcing of their product. These benefits may justify the burden of compliance (Ladanai and Vinterbäck 2010). Furthermore, implementation, verification, and monitoring are key factors for ensuring long-term success (Scarlat and Dellemand 2011).

The agronomics for different biofuel feedstock entail different management practices and outcomes (Mitchell *et al.* 2012). As such, the impact of crop agriculture, forest biomass, energy crops, such as switchgrass, on the physical, biological, and chemical properties of soil, hydrology and water quality, site productivity and regenerative capacity, landscape, ecosystem, species, genetic biodiversity, net carbon sequestration and non-carbon greenhouse gases release, and socioeconomic performance cannot be assumed to be the same. Each factor may require different mitigation approaches and corresponding specialized criteria and indicators certifying the sustainable production of that feedstock (Stupak *et al.* 2011). The currently available biomass certification programs do not specifically address switchgrass-based bioenergy as a product; the agronomic recommendations do not specifically address switchgrass as a bioenergy feedstock separate from other types of biomass, or even the hay and forage end use of switchgrass production (Mitchell *et al.* 2008). This lack of clarity could reduce transparency and increase conflict in meeting the economic, ecological, and social sustainability criteria and inherent tradeoffs. For example, winter switchgrass harvesting enables higher biomass recovery, stand productivity, and persistence, and it reduces the availability of nitrogen in the biomass that enhances conversion efficiency and its overall economic performance (Mitchell *et al.* 2012). Delaying harvest until spring provides nesting and winter wildlife cover that enhances its ecological performance, but results in lower yields (Vogel *et al.* 2002; Adler *et al.* 2006). Such tradeoffs are better accounted for in specialized certification programs.

Despite some common management and harvesting practices, the different objectives of bioenergy farming through the maximization of dry material, compared to maximizing quality when switchgrass farming is practiced for the purpose of foraging, leads to inherently different variations in farm management, harvest, and storage practices (Mitchell *et al.* 2008). Thus, featuring the growth of switchgrass for bioenergy feedstock in farmland management plans and relevant certification programs is merited (Vis *et al.* 2008; Ladanai and Vinterbäck 2010). Open-ended biomass certification programs such as the initial Round Table on Sustainable Palm Oil (RTPO), which did not specify end use, missed the opportunity to avoid unintended impacts such as using drained peat lands to grow palm trees for bioenergy. This created a substantial net CO_2 loss from using bioenergy (Vis *et al.* 2008). By accounting for the end use of the biomass key indicators, such as lifecycle GHG balance, net energy balance and eligible land use-related criteria should be featured in certification protocols. Compared to generic and open-ended certification protocols, switchgrass and bioenergy end-use specialized certification programs mitigate ambiguity, account for distinct attributes, contribute to a more transparent conduct, and enhance the overall effectiveness of certification processes (Cramer *et al.* 2007; Vis *et al.* 2008).

The potential for the sector's growth notwithstanding, there is limited experience in large-scale switchgrass production for bioenergy purposes. This results in many unknowns, and the creation of a standard protocol is strategic.

More specialized best-management practices and agronomic recommendations can be featured in these protocols, unlike a generic, all-encompassing biomass production or marketing sustainability certification protocol. These protocols allow for switchgrass-specific criteria and indicators and ensure sustainable switchgrass production for bioenergy use. For instance, clearly articulating specialized criteria and indicators creates an opportunity to plan for contingencies, such as the potential invasiveness of switchgrass in large-scale monoculture energy plantations, especially in areas where switchgrass is a non-native crop (Rinehart 2006).

Its application can also have spillover effects, where switchgrass growers apply or adapt these protocols to other farm practices. This can include practices such as livestock and agroforestry management, increasing the overall acreage of biomass production, and the breadth of farm practice conducted sustainably.

A switchgrass-focused certification protocol gives enforcement agencies relevant metrics to govern an emerging industry and assess the adherence of farmers to predetermined principles (Cramer *et al.* 2007). Currently, there are limited energy and environmental policies in the United States that explicitly account for switchgrass and corresponding sustainability certification protocols. This provides an opportunity for the creation of a specialized set of criteria and indicators (Cramer *et al.* 2007). Beside the synergistic benefits of covering the broader attributes of switchgrass production and warranting higher levels of sustainability, the integration of a specialized certification program and relevant energy and environmental policies could support these standards.

Additionally, there is an opportunity for increased integration between agricultural production of energy crops, such as switchgrass, and energy certification protocols (Vis *et al.* 2008; Ladanai and Vinterbäck 2010). This can improve upon and expand coverage of green electricity certification efforts, such as Green-e, which consider all energy crops as eligible for renewable electricity certification, given that they have less than a 10-year rotation cycle, do not displace food production, and do not use land that has been farmed in the previous two years (Green-e 2014).

Such efforts can be scaled up by making up for the limited number of eligibility criteria and indicators and by expanding the number of states where the program runs. Through specialized criteria and indicators, such certification protocol can be better integrated with the emissions trading schemes to create a mutually reinforcing synergy of an energy services that has a lower carbon footprint while potentially directing more funds towards the industry's growth (Ladanai and Vinterbäck 2010).

Specialized certifications create opportunities for greater integration of environmental and bioenergy development programs, such as the Biomass Crop Assistance Program (BCAP). BCAP provides financial incentives to growers of biomass crops to turn it into bioenergy feedstock. Additionally, the Conservation Reserve Program (CRP) encourages environmentally beneficial practices through the conservation and restoration of sites. This can take the form of integrating CRP enrollment eligibility criteria and performance standards from the certification program to ensure higher levels of sustainability, while also providing additional incentives that benefit growers and the bioenergy industry alike. Similarly, other environmental programs focusing on such aspects as biodiversity can be integrated with such a certification scheme for a synergistic effect that enhances dual outcomes.

RESULTS AND DISCUSSION

Suggested Criteria, Guidelines, and Indicators

The criteria developed in this paper build on existing standards and certification protocols to build specific guidelines for switchgrass-based biofuels. They are informed by agronomic recommendations for growing switchgrass as a bioenergy feedstock and attempt to balance the high-yield objective with broader economic, ecological, and social considerations.

These criteria and indicators are not necessarily exclusive of one another. For example, land use enhancement measures may also have profitability implications. The criteria and indicators presented here highlight the unique attributes, opportunities, and challenges of switchgrass that should be featured in the specialized certification protocol and should encompass other general biomass sustainability production standards. This includes the overall contribution to the enhancement of social, economic, and environmental wellbeing through criteria and indicators dealing with labor conditions, local job creation, and protection of vulnerable areas. We attempted to delineate both quantitative and qualitative criteria and indicators covering the entire lifecycle, beginning with land use and the cultivation of the raw materials, to the end use of the product and waste disposal. While some prescribed elements can be applied generally and guide relevant policies, others can be adapted to specific regional circumstances and other contextual variations to account for heterogeneity. These guidelines should incorporate feedback from key stakeholder groups in order to enhance their acceptance and implementation.

The impact categories include land use change and competition with food crops, agrochemical application, site establishment and harvest, biodiversity, water, waste management, economic sustainability, local and/or regional prosperity and social well-being, air quality and GHG emissions, as well as monitoring and verification. The criteria and guidelines shed light on the proposed objectives under each impact category, whereas the indicators present potential pathways to adhere to the prescribed course of action and encompass measurable outcomes and/or qualitative indicators that can be evaluated over time.

Land use change and competition with food crops

The development of switchgrass-based biofuels at a viable commercial scale that ensures a reliable and consistent feedstock supply for a conversion facility will require large areas of land for switchgrass cultivation (Rinehart 2006; Mitchell *et al.* 2012). Moreover, the land requirement for setting up preprocessing and conversion facilities is likely to be substantial (NRDC 2014). Factors such as former land use and land cover, site productivity, and terrain suitability, will affect the sustainability of potential large-scale land use change.

Agrochemical application

Switchgrass cultivation practices will likely limit the use of agrochemicals and will reduce ecological impacts as a result. Cultivators must adopt practices to ensure the efficient use of nutrients, maintain the quality of soil, provide greater resources and coverage for microbes, and reduce the need for agrochemical application. With these guidelines, cultivators can utilize sustainable alternatives and minimize unintended consequences of rampant agrochemical use.

Table 2. Criteria, Guidelines, and Indicators for Agrochemical Application

Criteria and Guidelines
2.1 Perform soil test at potential root depth to test for soil pH, availability of phosphorous, potassium and other nutrient availability to assess if it is within range and to take corrective measures.
2.2 Limit N application and adapt use to suit site fertility, timing of establishment, plant N fixing ability, and availability of legumes that fix N. Reduce presence of Nitrogen in biomass to help conversion efficiency of cellulose into fermentable sugar and reduces air potential air pollution associated with combusting biomass with high nitrogen presence.
2.3 Periodically test for N and other nutrient abundance in the root zone soil profile and its infiltration to groundwater.
2.4 Reduce presence of residue from previous land use and weed seed in the root depth soil profile to reduce revival during fertilization and application of other nutrients.
2.5 Adapt application rate and timing to cultivar, other management practices, precipitation, and soil and site characteristics.
2.6 Use growing season or cool season specific chemicals and prescribed by local best management practice application rates per acre.
2.7 Minimize use of herbicidal control and adopt adequate weed control management techniques during establishment to reduce requirements in the following years and limit weed competition for resources with switchgrass to improve stand success.
Indicators
2.1 Documentation indicating tests that identify optimal application rates ensuring minimal or no run-off and infiltration to groundwater systems.
2.2 Rotation cycle readings on pH, soil nutrient content test.
Sources: Martin *et al.* 1982; Muir *et al.* 2001; Vogel *et al.* 2001; Vogel *et al.* 2002; Hanson *et al.* 2005; Fike *et al.* 2006; Mulkey *et al.* 2006; Cramer *et al.* 2007; Lee *et al.* 2007; Mitchell *et al.* 2008; Mitchell *et al.* 2012; NRDC 2014.

Establishment and harvest

Switchgrass requires about three years to become established and to reach full yield potential. Therefore, cultivators must continue to follow updated best management practices (BMPs) to enhance biomass yield. Establishment rates and yield vary based on region, switchgrass variety, and ecotype (Wright 2007).

Cultivators should seek guidance about region-specific cultivars based on the latest breeding and genetics research, and their specific hardiness zone to avoid winter stand loss, attain optimal flowering time, and reduce economic risk. They should also follow stated BMPs in regards to the portion of the harvest that should be left on the ground as an organic nutrient source for subsequent years.

Table 3. Criteria, Guidelines, and Indicators for Stand Establishment and Harvest

Criteria and Guidelines
3.1 Establish through no-till planting and minimize use of conventional tillage and drill planting. If drill establishment is required, documentation should show that the tradeoff in cost, soil quality, and net energy balance change should justify such establishment method.
3.2 Renovate stand with higher yielding material if stand success rate is low by reestablishing stand with different input and management techniques to ensure full term high yield stand starting from the panting year.
3.3 Harvest in annual or biannual cycles to ensure survivability and productivity. If conservation land is used to grow switchgrass, then delayed harvest may be considered. Allow for full senescence before winter harvest to reduce fertilization needs.
3.4 Harvest a few inches above ground to minimize disturbance to winter cover and nesting function of the switchgrass cropland and to avoid disturbing the soil organic carbon (SOC) storage at deep root levels.
3.5 Ensure that harvest levels do not exceed minimum critical biomass density per area and to maintain integrity of the soil stability, organic matter richness, and continued SOC storage.
3.6 Stalk bale in uniform sizes to ease arrangement for storage, save on space and volume per weight, help transportation cost, utilize all space available, eases management, maximize use employment of existing baling, handling, hauling, and processing systems without an expensive retrofitting or specialized equipment. This practice enhances volume per weight for storage and transportation purposes, and reduces pre- processing drying need.
3.7 Store harvest in an enclosed area or cover with hay trap to limit biomass quality loss, spoilage, and maintenance of extractable ethanol content.
Indicators
3.1 Quantity of dry matter weight loss and changes in moisture content.
3.2 Quantity of SOC storage and soil organic matter at switchgrass root levels.
3.3 Percentage of potential production that can be harvested the year of planting and number of years before full potential production is achieved.
3.4 Saving on time, fuel, labor and other costs and trend in establishment and management cost.
3.5 Adherence to harvesting and storage guidelines to meet conversion facility procurement requirements
Sources: Panciera *et al.* 1984; Vogel *et al.* 1987; Wiselogel *et al.* 1996; Sanderson *et al.* 1997; Smart *et al.* 1997; Martinez-Reyna and Vogel 2002; Vogel *et al.* 2002; Frank *et al.* 2004; Vogel *et al.* 2004; Bransby *et al.* 2005; Liebig *et al.* 2005; Vogel *et al.* 2005; Fike *et al.* 2006; Schmer *et al.* 2006; Perrin *et al.* 2008.

Biodiversity

Conserving and maintaining species diversity, native habitats, and ecosystems are important responsibilities that have been repeatedly safeguarded through legislative statutes (NRDC 2014). Switchgrass is an excellent habitat for wildlife species because it provides suitable nesting sites and protection from predators (Renz 2009). As noted in Cramer *et al.* (2007), it is important that plantations not be located near areas of high conservation value or in areas that have high natural and/or cultural value. The primary goal is to maintain habitat integrity and stimulate growth in an effort to minimize impact on plant community diversity.

Table 4. Criteria, Guidelines, and Indicators for Biodiversity

Criteria and Guidelines
4.1 Plantations should not be established in areas switchgrass is not native to or should be done with the extra responsibility of ensuring no or minimal impact takes place in terms of becoming weedy or invasive or displacing other local vegetation and negatively affecting the background ecosystem's stability.
4.2 Minimize interference with regular maintenance and spread of wildlife; avoid fragmentation of unique habitats, and ecological corridors.
4.3 Preparation of conservation plan to include plan for protection/enhancement of species/ecosystems that are likely to be impacted.
4.4 Monitor for outbreak of grasshoppers, leafhoppers, switchgrass moth, and armyworms and other common switchgrass pests around switchgrass plantations. Participants must demonstrate preparedness for response to potential disease, insect pest, and invasiveness of switchgrass associated with large-scale dedicated plantations.
4.5 Minimize the chances of such outbreak by using pathogen screened and certified seeds.
4.6 Maintain regular communication channel with local extension workers for region specific updates on outbreaks and other updates on agronomics and best management practices.
4.7 Place restrictions on biomass harvest during critical breeding/hatching season.
Indicators
4.1 Monitor trends in local biodiversity index.
4.2 Monitor ecological corridors and provision of appropriate surrounding buffer zones where necessary.
4.3 Periodic evaluation of conservation plan to assess adherence to plan objectives.
4.4 Frequency and impact of plantation on overall community's agricultural stand, productivity, yield and quality level resulting from pest outbreaks and switchgrass invasiveness.
4.5 Frequency and acreage of controlled burning in a rotation cycle.
Sources: Sanderson *et al.* 1996; McLaughlin *et al.* 1998; McLaughlin *et al.* 2002; Casler *et al.* 2004; Masters *et al.* 2004; Vogel *et al.* 2004; Roth *et al.* 2005; Cramer *et al.* 2007; Lal *et al.* 2011; NRDC 2014.

Water

Switchgrass is a flood- and drought-resistant energy grass and as such, it requires less water than traditional row crops. While the specific water requirement for switchgrass biofuels may vary with the agricultural intensity and conversion technology adopted, water is an important resource both in the production and conversion processes (Earth Institute 2011). For example, switchgrass planted in the floodplains provides limited stress on already scarce water resources, but it also mitigates problems of soil erosion (Bardhan and Jose 2012). Global certification standards and biofuel policies emphasize the importance of sustainable water use and the protection of water bodies (Van Dam *et al.* 2008). Not paying adequate attention to the water requirements along the biofuel supply chain could result in negative consequences for the economic prosperity and health of local communities (NRDC 2014). The production of biofuels from switchgrass must not deplete surface or ground water while maintaining the quality of water.

Table 5. Criteria, Guidelines, and Indicators for Water

Criteria and Guidelines
5.1 Preparation of a comprehensive water management plan including estimates on water requirements, availability, and usage by cultivators and conversion facilities. 5.2 Frameworks to avoid contamination of ground and surface water resources. 5.3 Documentation of existing characteristics of local water sources including physical and chemical attributes to serve as a baseline. 5.4 Treatment of wastewater containing contaminants that can impact human or ecosystem health including wildlife, soil, and water resources.
Indicators
5.1 Evidence indicating adherence to federal/state BMPs. 5.2 Periodic assessment of physical and chemical attributes of local water resources to ensure maintenance of baseline characteristics, ensuring that non-renewable water sources are not are not depleted or contaminated. 5.3 Steps taken for reusing or recycling wastewater, demonstration of improvement in water efficiency.
Sources: Cramer *et al.* 2007; Lal *et al.* 2011; RSB 2013; NRDC 2014.

Waste Management

Agricultural and industrial processes result in a range of by-products and waste material that must be handled appropriately. Careful handling ensures that the production of biofuels does create unintended environmental damages and problems.

Table 6. Criteria, Guidelines, and Indicators for Waste Management

Criteria and Guidelines
6.1 Develop recycling strategies and minimum waste plans or "zero waste" goals. 6.2 Minimize risk of damage to environment and human life through proper storage, handling, and disposal of chemicals and hazardous wastes as well as microbes/catalysts uses in biofuel operations according to federal regulations and guidelines.
Indicators
6.1 Demonstrate material efficiency improvements in feed stock production and conversion processes. 6.2 Document evidence indicating compliance with regulations pertaining to storage, handling, and disposal of chemicals and hazardous wastes.
Sources: RSB 2013; NRDC 2014.

Economic sustainability, local/regional prosperity, and social well-being

The biofuels industry, along its entire product life cycle, provides the potential to boost agriculture and industrial activity and to create domestic employment in both direct and indirect pathways. However, the financial viability of feedstock production or conversion processes is central to the long-term sustainability of the industry (NRDC 2014). Furthermore, the benefits associated with the development of a new industry should reach individuals engaged directly, such as employees and local communities (Cramer *et al.* 2007). As a result, the specific socioeconomic impacts as well as direct and indirect contributions the local/regional economy should be measured using simple input-output models or freely available tools such as the Jobs and Economic Development Impact (JEDI) model developed by the National Renewable Energy Laboratory (NREL).

Table 7. Criteria, Guidelines, and Indicators for Economic Sustainability, Prosperity, and Social Well-Being

Criteria and Guidelines
7.1 Stream of income over rotation cycle should indicate preferable return compared to other land uses and biomass production.
7.2 Progress towards competitive pricing of switchgrass compared to other feedstock through cost reducing measures as using marginal land or other land with lower opportunity cost
7.3 Contribution of the bioenergy industry to spur local economic activities
7.4 No negative influence on working conditions, land/property rights and human rights
Indicators
7.1 Trend of acreage enrolled in land devoted solely to switchgrass cultivation or through intercropping.
7.2 Profit per acre on cultivation and harvest for switchgrass
7.3 Direct economic value created, number of direct jobs (local and regional) and approximate indirect jobs attributable to the industry.
7.4 Trends in average work hours, per capita income and local/regional income inequality attributable to bioenergy related activities
7.5 Number of land/property ownership conflicts
Sources: Rinehart 2006; Cramer *et al.* 2007; Mitchell *et al.* 2008; Perrin *et al.* 2008; Lal *et al.* 2011; Mitchell *et al.* 2012; NRDC 2014.

Air quality and GHG emissions

The transition towards biofuels is designed to mitigate the negative effects of fossil fuel dependence. Therefore, it is important to consider the local air quality and global GHG emission that result from biofuel use. While some of the criteria mentioned in Table 1B, such as land use change, will contribute to the GHG balance, it is important to specify standards that focus on GHG emissions and air quality. In addition, using Life Cycle Analysis (LCA) tools, such as GREET, could be useful to strengthen the measurement aspects associated with GHG emission reductions.

Table 8. Criteria, Guidelines, and Indicators for Air Quality and GHG Emissions

Criteria and Guidelines
8.1 Evaluation of emissions and criteria pollutants from cultivation and conversion processes and development of air management plan
8.2 Lifecycle GHG emissions for switchgrass-based biofuels should be lower than the associated fossil fuel baseline
Indicators
8.1 Reduction of GHG emissions by 50-70 percent for electricity production and 60 percent for biofuels with periodic reviews to match global best practices
8.2 Annual report of air emissions and comparison with baseline
8.3 Third party audits of GHG lifecycle inventory and emission estimates
Sources: Cramer *et al.* 2007; RSB 2013; NRDC 2014.

Monitoring and verification

As part of the endeavor toward sustainable production of switchgrass-based bioenergy, periodic internal audits of the certification, and subsequent external audits, are encouraged to affirm management's commitment to employees through the entire process of biomass and biofuel production. This includes biomass/biofuel handling, transport, storage, conversion, distribution supply chain, sub-contractors, and end users. The audit should evaluate attainment of continued compliance and operational targets. The audit should aim to build on measures that contribute to greater compliance and/or take corrective and preventive actions to ensure an active engagement in sustainability practices.

Table 9. Criteria, Guidelines, and Indicators for Monitoring and Verification

Criteria and Guidelines
9.1 Periodic internal and external audits to ensure adherence to targets and guidelines
9.2 Public dissemination of certification protocol related obligations and audit results publicly available
Indicators
9.1 Availability of internal/external audit reports pertaining to the product life-cycle in publicly accessible formats such as print or on the organization website
Sources: Cramer *et al.* 2007; Ismail *et al.* 2011.

Documents submitted in support of the application, and those detailing the results of the latest internal and external audits, must be produced and must account for a substantial portion of the total biomass/biofuel production transactions completed by the applicant. The application should be subjected to tests of internal consistency and reviewed by external accreditors. The certification system and the applicant may use these standards to evaluate compliance trends over the duration, identification, and targeting of operational challenges and opportunities that are better captured by long- term data. Collection of this data can help realign the criteria and indicators to practical issues and considerations that surface over time.

Furthermore, information provided by a supplier regarding its product, technology, price and other details, should be accurate, up-to-date and relevant. Attributes of the product supply chain, ranging from feedstock cultivation, conversion, and end-use, that ensure long-term sustainability and environmental stewardship, should be articulated in the monitoring process. The claim of product compliance with certification standard should be based on the final bioenergy product that is derived from certified switchgrass.

Discussion and Future Work

The agronomy and conversion of switchgrass into bioenergy is not identical to that of other feedstocks. This demonstrates the need for and presents an opportunity to develop switchgrass-specific criteria and indicators that account for its agronomic attributes, incorporate best management practices from other biofuel certification systems, and are rigorous yet practical from an implementation perspective. The target of such standards and protocols is to ensure development of switchgrass-based bioenergy that realizes the potential benefits of second-generation bioenergy, while safeguarding from the potential adverse outcomes. These standards complement existing standards and regulations, and provide specialized criteria and indicators to relevant stakeholders. This will build consumer confidence and provide credibility to an industry that is still in its nascent stages of development. It will also build acceptance for the product across the supply chain, including the handling, transport, storage, and distribution. The recommended certification criteria and guidelines should be complemented with life cycle assessments that will ensure that the overall life cycle performance of switchgrass-based bioenergy achieves its intended outcome.

The market for switchgrass-based bioenergy is likely to evolve substantially over the next few years, which will necessitate a review of the current standards and protocols. Future research can verify and adapt the genetic, breeding, establishment, and management research on switchgrass across agro-ecological regions that focuses on yield, quality, insect and disease resistance, livestock forage, and its use as a biomass energy crop (Mitchell *et al.* 2012). For instance, as the switchgrass stand matures and harvestable dry mater increases, the carbohydrate and lignin composition changes, reducing the efficiency of recovering fermentable glucose (Dien *et al.* 2006). Future research can determine the best way to manage, harvest, process, transport, convert, and distribute energy from switchgrass. Future agronomic research can also investigate the response of switchgrass bioenergy production to nutrients, and how their application rates should be adapted to factors such as precipitation, chemical and biological attributes of soil, *etc.* (Mitchell *et al.* 2008). Research can also devise methods to reduce biomass weight loss, quality loss, spoilage, and reduce pre-conversion management needs and associated economic and net energy losses. In addition, it is necessary to adapt the certification standards to various geographic, sociopolitical, economic contexts. Another important aspect associated with the implementation and widespread acceptance of a certification standard concerns the burden of costs and accrual of benefits from certification. The sustainable production of switchgrass-based bioenergy will not only result in greater societal benefits from an environmental perspective, but also result in a range of benefits for stakeholders who are directly and indirectly involved in the production and distribution of the product itself. The suitability of participatory mechanisms to determine appropriate cost-sharing frameworks and use of technological inputs to facilitate ease of monitoring and verification are also important avenues for future research. Finally, the efficiency of certification criteria, and the marginal benefits arising from certification must be evaluated and validated through field-based assessments.

In order to maximize the benefits accruing from improved resource allocation and monitoring using metrics such as net GHG, and energy balance associated with some of the impact categories, it is necessary to develop easy-to-use tools that are readily accessible. Outreach programs can work on devising ways to ease the complexity in developing, managing, and communicating information about switchgrass specialized criteria indicators to all product users. Furthermore, we can design frameworks that regulate the industry and maximize the benefits accruing to the industry participants, without inhibiting growth opportunities whilst ensuring economic and environmental sustainability. Additionally, future research can assess and enhance the congruence of the protocol's criteria and indicators with international trade laws and agreements to reduce their chance of becoming trade barriers especially if the certification protocols are not running concurrently among the trading parties in switchgrass-based bioenergy products. Given the potential for switchgrass based biofuels, future research can devise an effective operational management strategy and update the criteria and indicators to benefit from new research and field experience.

These criteria, guidelines, and indicators are meant to initiate a broad-based discussion and guide policy development around creating standards that are easily implementable and ensure wider acceptance from all stakeholders. Using switchgrass as an example, we have delineated some of the most crucial aspects of developing a feedstock specific certification program that can be used a blueprint for other bioenergy feedstocks. The implementation could involve regulations or voluntary compliance, which can be subsequently updated based on field experience, local priorities, higher weightage to indicators that require urgent attention, and site-specific conditions that are in congruence with the larger objectives of the country's energy policy.

CONCLUSIONS

1. Biomass certification programs exhibit differences in terms of generalizability, end use specificity, and applicability across the supply chain, and a one-size-fits-all approach will not be useful in certifying biofuels produced from different feedstock.
2. Specific guidance documents, such as this paper, have not been developed earlier, and the methodological aspects highlighted herein can be adapted for other biomass crops/feedstocks.
3. Integration of switchgrass-specific agronomic recommendations, best management practices, and research with a more broadly applicable and practical set of criteria and indicators can provide a robust switchgrass-focused biofuel certification system.
4. The proposed criteria and indicators encompass nine impact categories including land use, agrochemical application, stand management and harvest, biodiversity, water, waste management, socioeconomics, air quality, and monitoring. These indicators can help realize the benefits of switchgrass-based bioenergy while safeguarding from potential risks.

ACKNOWLEDGMENTS

The authors are grateful for funding from the U. S. Department of Energy award number DE-P10000031 and the Joint Clean Energy Research and Development Center (JCERD).

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Article submitted: April 5, 2016; Peer review completed: May 29, 2016; Revised version received and accepted: June 24, 2016; Published: July 11, 2016.
DOI: 10.15376/biores.11.3.7102-7123