LIFE CYCLE ASSESSMENT OF REGIONAL SWITCHGRASS FEEDSTOCK PRODUCTION COMPARING NITROGEN INPUT SCENARIOS AND LEGUME-INTERCROPPING SYSTEMS

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INTRODUCTION

As the use of second-generation biofuel crops increases, so do questions about sustainability, particularly their potential to affect fossil energy consumption and greenhouse gas (GHG) emissions. This study used life cycle assessment (LCA) to compare environmental impacts associated with three switchgrass (*Panicum virgatum* L.) production scenarios:
i) regional production from a pool of Tennessee farmers based on in-field inputs and biomass yield;
ii) varying nitrogen (N)-input levels i.e., a 100% and 9% decrease, and an 81% and 172% increase from 'baseline levels' of N inputs used under scenario i; and,
iii) legume-intercrop system compared to baseline levels in order to determine effects of displacing synthetic-N with legumes (Fig. 1, A1).

MATERIALS AND METHODS

Life cycle inventory (LCI) was modeled with SimaPro LCA software, which calculated the overall cradle-to-gate emissions associated with production processes (Fig. 1), Reported data were collected in accordance with ISO 14,040 and 14,041 standards (ISO, 2006). Upstream processes in the reference system not explicitly examined in our research (e.g., equipment-use hours, electricity, diesel, and production of: fertilizer, seed, herbicide, and surfactant, as well as GHG emissions emitted during these processes) were taken from the US LCI Database in SimaPro (Pré Consultants, 2012). Life cycle impact assessment (LCIA) was conducted using the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI 2.0) model (USEPA, 2002) to determine mid-point indicators.

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REFERENCE SYSTEM BOUNDARY

Environmental mid-point impact categories of global warming (kg CO_2-eq.), acidification (H^+ moles-equivalent per kg of emission deposited), carcinogens (kg benzene-eq.), non-carcinogens (kg toluene-eq.), respiratory effects [particulate matter (PM 2.5-eq.)], eutrophication (kg N-eq.), ozone depletion [chlorofluorocarbons (kg CFC-11-eq.)], ecotoxicity (2, 4-D-eq.), photochemical ozone creation potential [POCP (kg NOx-eq.)], and global warming potential [GWP (kg CO_2-eq.)] were examined. LCIA functional unit (allows for standardization): 1 ton (2000 lbs = 907 kg) of DW switchgrass biomass (standard unit in commerce).

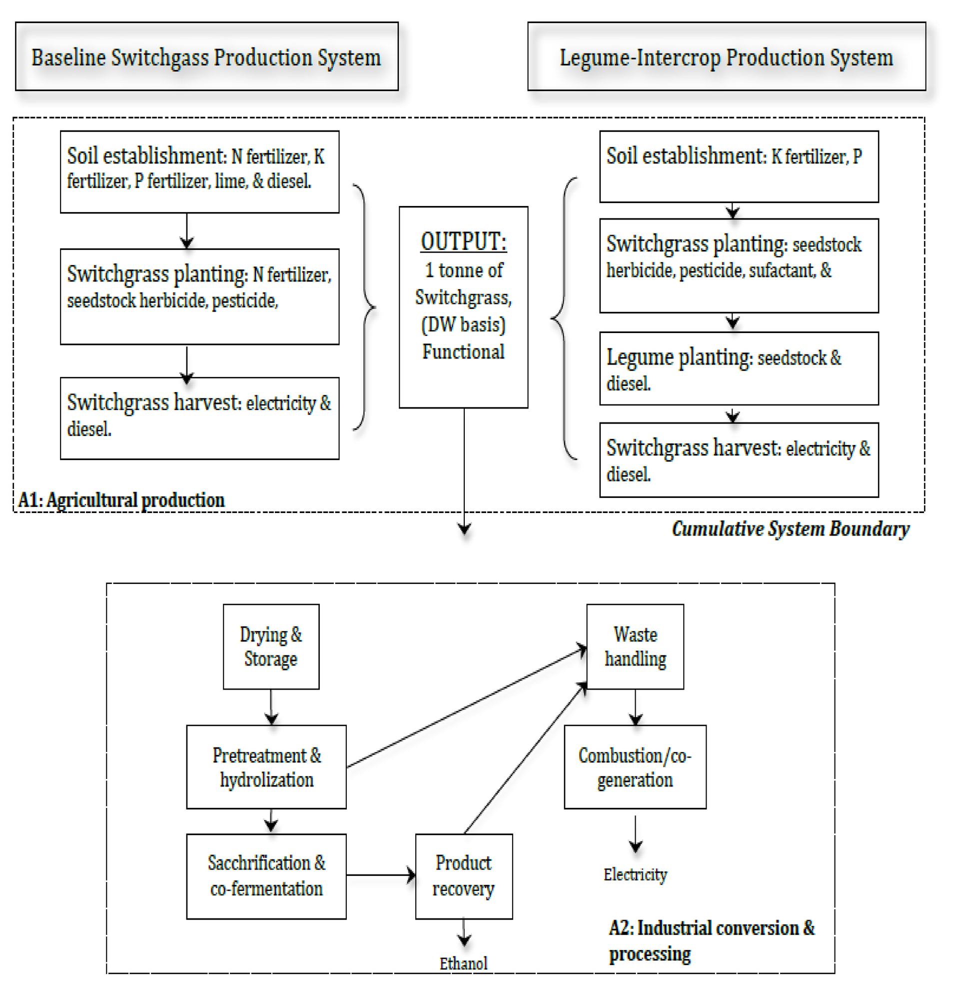

Figure 1. Life cycle analysis system boundaries, including both the agricultural production (A1) phases and industrial conversion and processing (A2) steps.

1.1. *Regional baseline switchgrass production scenario*

The LCI in-field data were derived from a UT Biofuels Initiative survey to 61 participating farmers and provides input, growth, and harvest data for 2008, 2009, and 2010 (Reed, 2012; Table 1). Data were weight-averaged over a ten-year period (due to yield asymptote in year three). Assumedly, biomass was harvested and field cured (<20% MC).*Results from this survey established 'baseline N-levels.'

Table 1. Cradle-to-(farm) gate LCI inputs per one Mg dry matter of switchgrass in the southeast. Input values are averaged over a 10-year production cycle.

Inputs	Units	Average value[a]	Coefficient of variation[b]
Diesel (tractor use)	L	3.98	46%
Nitrogen (fertilizer)	kg	4.77	84%
Phosphorous (fertilizer)	kg	0.49	224%
2, 4-D (pesticide)	L	0.05	219%
Glyphosate (herbicide)	L	0.05	213%
Surfactant	L	0.03	332%
Seed[c]	kg	0.56	n/a

[a] Average value is the weighted average over a 10-year switchgrass stand rotation, where inputs and yields are assumed to be constant in years 3-10.
[b] Coefficient of variation is standard deviation/average of the reported data, without any weighting for stand age.
[c] Seed input values were not reported by the farmers, however a 7.84 kg ha^{-1} PLS rate was assumed once over a 10- yr life cycle.

1.2. *Switchgrass feedstock production under nitrogen input scenarios*

Sensitivity analyses were conducted based on local switchgrass N-input response data. Nutrient response LCI data were collected by Mooney et al. (2009) at four locations in Tennessee for an 8-yr period and over a range of soils [two Grenada silt loams, Vicksburg silt loam, and a Collins silt loam (Table 2)]. Fertilizer treatments in this study were 0, 67, 134, and 201 kg N ha^{-1} after year one. Switchgrass was harvested annually following a first-killing frost.

Table 2. Measured switchgrass dry matter yield (± one standard deviation) for sensitivity analyses averaged across N-inputs for 10 yrs. at four locations in Tennessee.

Scenario	N-input[a]	Relative to baseline	Yield
	----kg ha^{-1}----		----kg ha^{-1}----
Sensitivity # 1	0	-100%	5.68 ± 1.9
Sensitivity # 2	60.5	-9%	8.43 ± 2.6
Sensitivity # 3	121.0	+81%	9.18 ± 2.9
Sensitivity # 4	181.5	+172%	9.83 ± 3.1
Baseline level	66.6	0%	6.98 ± 2.9

[a] Nitrogen input scenario sensitivities 1, 2, 3 and 4 (or 0, 67, 134, and 201 kg N ha^{-1}, respectively) and baseline N-levels weight-averaged over 10 years and divided by yield data for 10-yrs in order for functional unit standardization.

1.3. *Life cycle analysis of switchgrass-legume intercropping scenario*

LCI based on regional in-field data (Ashworth et al., 2011) assumes legume (i.e., red clover) planting occurred two and a half times over a 10-year simulation period. Input assumptions: legume seed and diesel for a single planting were multiplied by 2.5; a 0% yield reduction compared to LCA in scenario i.; a 13.4 kg ha^{-1} PLS legume seeding rate; same P and K inputs under scenario i; and, 0 kg ha^{-1} N was needed over the entire simulation period. Other published clover inventory data with the SimaPro database were used for upstream simulation of legume cropping systems.

RESULTS

1.1. *Regional baseline switchgrass production scenario*

Important regional switchgrass production inputs (>50% portion of the total impact) were nitrogen and phosphorus (P) fertilizer, diesel fuel, and glyphosate herbicide (Fig. 2). Diesel inputs into switchgrass systems impacted POCP and ecotoxicity. Glyphosate production and utilization greatly impacted ozone depletion.

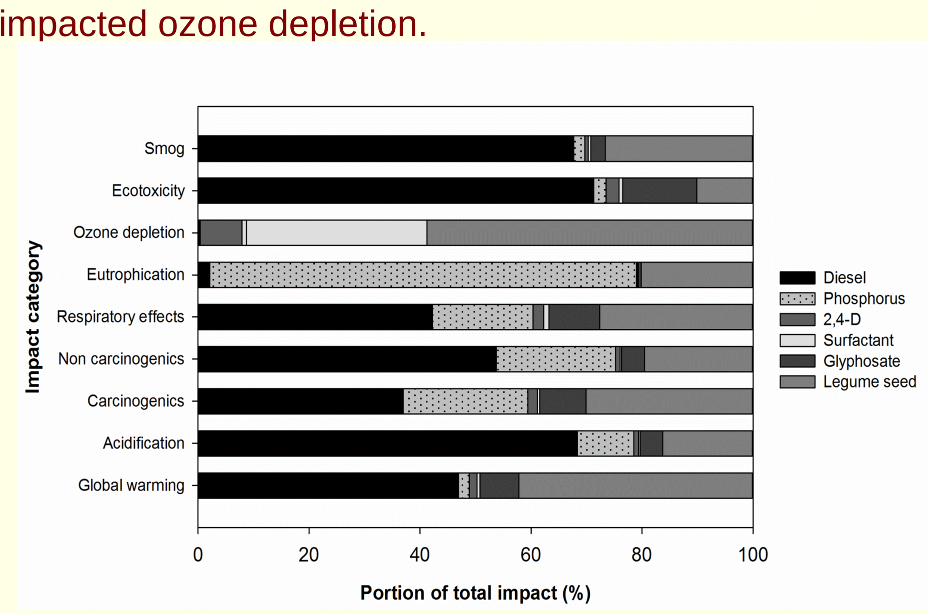

Figure 2. Impact categories and their relative impact proportion based on system inputs for baseline production (UTBI switchgrass farmers, based on 10 yr. simulation period).

1.2. *Switchgrass feedstock production under nitrogen input scenarios*

Relative environmental impacts from N-input scenarios indicate trade-offs on aggregated impact categories (Fig. 3). Sensitivity # 4 (181 kg N ha^{-1}) rate resulted in the greatest acidification, carcinogenic, and eutrophication (on a per tonnage basis; Table 2). Sensitivity analysis #1 (or a 100% decrease from baseline levels of N) resulted in the least negative impacts across all categories except ecotoxicity and carcinogenics.

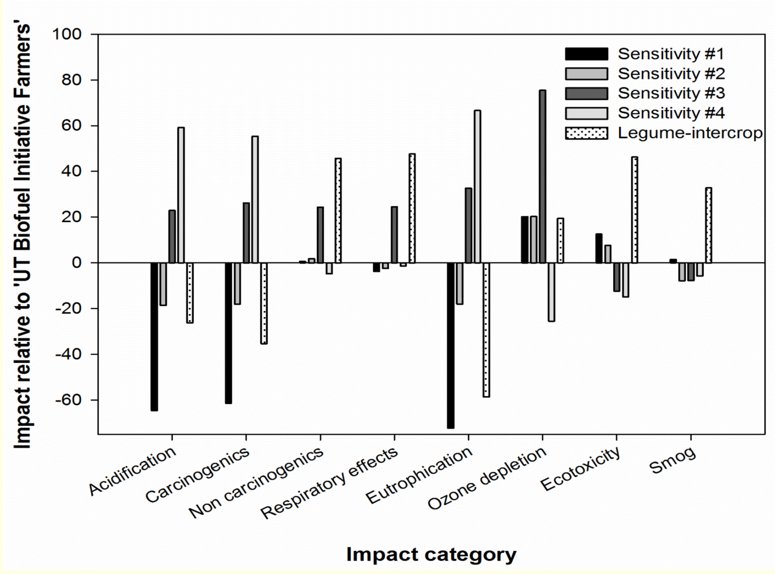

Figure 3. Impact categories and their relative impact proportion for nitrogen input scenario sensitivities 1, 2, 3 and 4 (or 0, 67, 134, and 201 kg N ha^{-1}, respectively) and baseline production from farmers with the UTBI (based on 10 yr simulation period). A negative relative impact indicates a positive impact.

1.3. *Life cycle analysis of switchgrass-legume intercropping scenario*

A substantial portion of environmental disturbance from diesel fuel, phosphorus, and seed inputs on impact categories occurred (Fig. 4). Namely, diesel inputs resulted in greater than 50% of the total impacts for acidification, non-carcinogenics, ecotoxicity, and smog. Relative to farmers with the UTBI, favorable impacts on acidification, carcinogens, and eutrophication occurred.

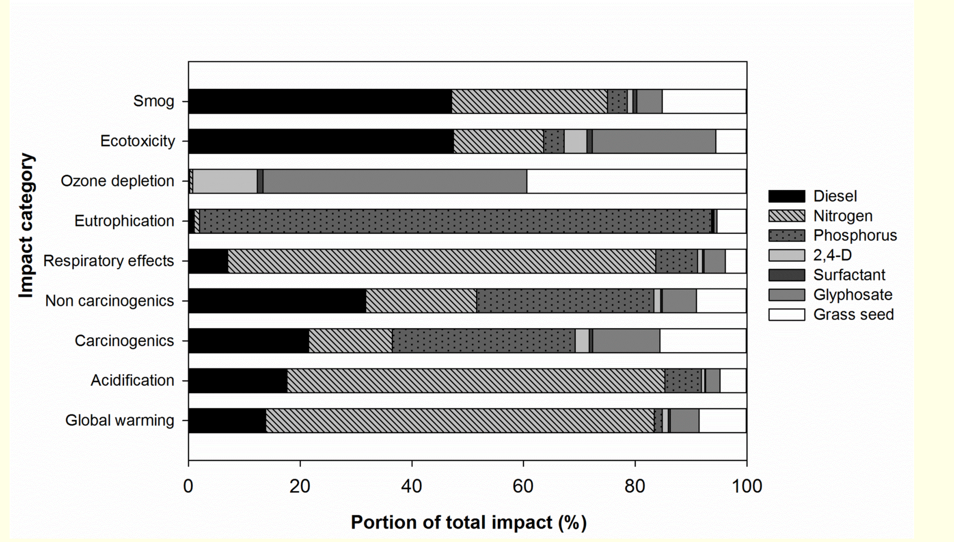

Figure 4. Impact categories and their relative proportion of impact based on system inputs for legume-intercropping in switchgrass feedstock production systems in the Southeast (based on 10-yr simulation period).

A 0 kg N ha^{-1} rate resulted in the least GHG emission production [on a per ton biomass basis; (Fig. 5)]. The legume-intercropping simulation resulted in fewer stratosphere-warming gases, albeit only slightly less than the Sensitivity #2 (current recommended N-rate for Tennessee).

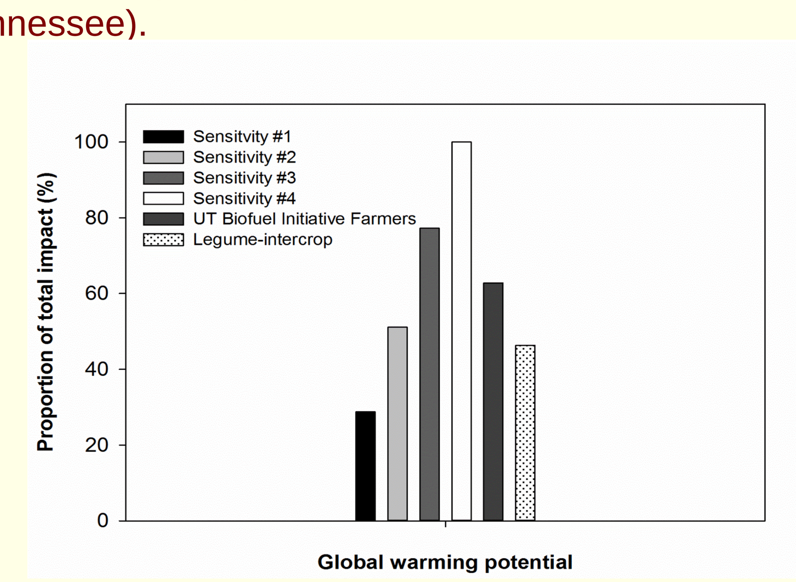

Figure 5. Global warming potential (kg CO_2-equivalents) of switchgrass production over a range of input levels (0, 67, 134, and 202 kg N ha^{-1}, Sensitivity #1-4, respectively), regional production from area growers, and a legume-intercropping scenario (based on 10-yr simulation period).

CONCLUSIONS

- Results indicate a 'less is more' scenario, as inputs beyond current recommended input levels (67 kg N ha^{-1}) are not remunerating in terms of nutrient response and subsequent environmental impacts.
- Overall, system inputs with lesser impacts included phosphorus, herbicides, pesticides, and diesel fuel.
- A 100% reduction in N-inputs from baseline levels resulted in the least negative impacts *per unit of production* (or DM ton of biomass over a 10-yr period) across all mid-point categories. This was due to switchgrass' relatively low N response.
- Legume-intercropping may reduce GHG emissions and groundwater acidification compared with the current recommended N-rate (i.e., a 5% and 27% reduction in GWP and acidification, respectively).
- Results imply N-fertilizers impact regional switchgrass feedstock sustainability; however, production can be sustainable under the current N recommendation.