Carbon debt of CRP and agricultural lands converted to annual vs. perennial bioenergy crops

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Introduction

The net greenhouse gas (GHG) fluxes of an ecosystem are directly influenced by land use conversions. In the USA, ~5 Mha of grassland in the Conservation Reserve Program (CRP) have been converted to agricultural production in response to higher demand for corn grain biofuel. The global warming impact (GWI) of these biofuel crops can remain positive for many years following the conversions. Model estimates suggest that 340 Mt to 351 $\times 10^6$ Mt of carbon dioxide equivalents (CO_2eq) would be released to the atmosphere after the conversions. These estimates, while highly uncertain, appear to have payback times of decades to centuries.

We converted CRP grassland and conventionally-tilled agricultural (AGR) land to grain (corn) and cellulosic (switchgrass and restored prairie) biofuel feedstocks. One CRP grassland (CRP-Ref) was left unconverted (Fig. 1a). We conducted life cycle analysis (LCA) on all converted lands by accounting for greenhouse gas fluxes related to farming operations, agronomic inputs, and soil-atmosphere greenhouse gas exchanges over 8 years from 2009−2016.

Objective

- To assess the 'carbon debt' payback time of grain and cellulosic biofuel crops following land use conversion.

Hypotheses

- Biofuel production on former CRP grasslands would create a large 'carbon debt' that would require many year to payback while on former AGR lands would result in carbon gain.
- Perennial biofuel crops would gain more or lose less carbon than annuals within the respective land use histories.

Experimental design

The experimental sites were located at the W. K. Kellogg Biological Station (42°24' N, 85°24' W, 288 masl) in Southwest Michigan within the US Corn Belt.

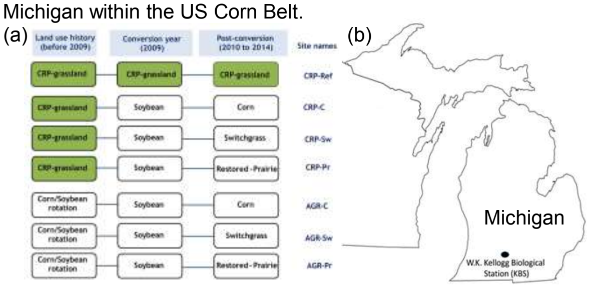

Fig. 1. Land use conversions from CRP and conventionally-tilled agriculture to soybean and to annual and perennial biofuels over time (a) and study site location (b).

GHG balance:

GHG balance = Agronomic inputs + Fluxes – Energy production where Inputs include farming fuel consumption, fertilizer, herbicides and seeds; Fluxes include N_2O, CH_4 and CO_2; and Energy production refers to bioethanol production.

Cumulative global warming impact (CGWI)

- All biofuel systems on former CRP had a positive CGWI (net emission, 'carbon debt') following conversion except in the last study year at CRP-Sw; whereas all systems on former AGR had negative CGWI (Fig 2).
- Corn system on former CRP (CRP-C) incurred the highest 'carbon debt' with estimated 390 years payback time;
- Restored prairie on former CRP (CRP-Pr) would likely payback its 'carbon debt' in the following year—9 years after conversion;
- Switchgrass on former CRP (CRP-Sw) paid its 'carbon debt' 8 years after conversion.
- The CRP-Ref had a positive CGWI after a drought year in 2012.

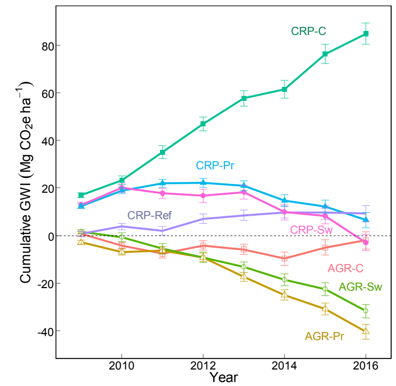

Fig. 2. Cumulative global warming impact of all bioenergy crops (2009–2016). Fields were converted from Conservation Reserve Program (CRP) grassland or conventionally tilled corn-soybean rotations (AGR) to no-till soybean in 2009 and to corn, switchgrass or restored prairie systems from 2010 onwards.

Individual GWI components

- Largest carbon cost contribution on former CRP lands was due to NEE_{adj} (Adjusted net ecosystem exchange: the sum of CO_2 flux and harvested C; Fig. 2);
- Perennial systems on former AGR lands exhibited negative NEE_{adj} while the corn system was slightly positive;
- Carbon cost of N_2O fluxes and farming operations varied according to management intensity regardless of land use history (corn > switchgrass > restored prairie = brome grass);
- Methane consumption rather than emission was observed in all systems, albeit very small;
- Fossil fuel offset credit followed biomass available for ethanol production with the rank order as follows: corn > switchgrass > restored prairie.

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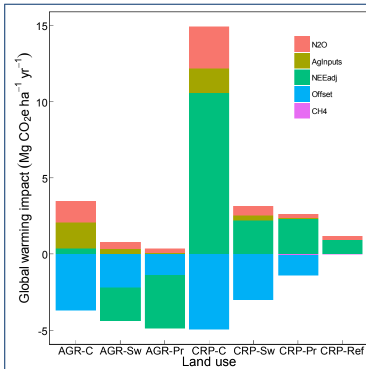

Fig. 3. CO_2eq of individual components contributing to GWI in all bioenergy systems (2009–2016).

CO_2eq emission reduction relative to fossil fuel

- Biofuel systems on former AGR fields showed a reduction while those on former CRP fields an increase in emission compared to fossil fuel lifecycle GHG emissions (Fig. 4);
- Cellulosic biofuel systems on former AGR fields met the 60% and corn grain biofuel system the 20% lifecycle GHG reduction compared to that of fossil fuel as stipulated by EPA.

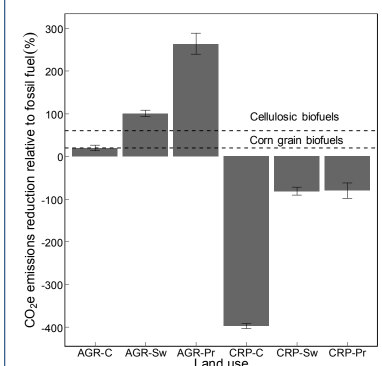

Fig. 4. Average emission reduction from all bioenergy systems compared to that of fossil fuel lifecycle GHG emission The dashed lines indicate the 20% and 60% emission reductions for corn grain and cellulosic biofuel crops, respectively, compared to that of fossil fuel).

Conclusions

- No GHG benefit from corn grain biofuel produced on former CRP lands, while marginal benefits are accrued from those produced on former AGR lands;
- GHG benefits could be reaped after ~10 years from perennial cellulosic biofuel systems on former CRP lands; while large GHG benefits could be achieved from first year of planting on former AGR lands.
- Models currently underestimate the 'carbon debt' payback time associated with conversion of CRP grasslands to bioenergy crops

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