Carbon debt of field-scale Conservation Reserve Program grasslands converted to annual and perennial bioenergy crops

Michael Abraha[1,2,3] , **Ilya Gelfand**[2,3,7] , Stephen K Hamilton[2,3,4] , Jiquan Chen[1,2,5] and G Philip Robertson[2,3,6]

[1] Center for Global Change and Earth Observations, Michigan State University, East Lansing, MI 48823, USA
[2] Great Lakes Bioenergy Research Center, Michigan State University, MI 48824, USA
[3] W K Kellogg Biological Station, Michigan State University, Hickory Corners, MI, 49060, USA
[4] Department of Integrative Biology, Michigan State University, East Lansing, MI 48824, USA

[5] Department of Geography, Environment, and Spatial Sciences, Michigan State University, East Lansing, MI 48824, USA
[6] Department of Plant, Soil, and Microbial Sciences, Michigan State University, East Lansing, MI 48824, USA
[7] The French Associates Institute for Agriculture and Biotechnology of Drylands, The Jacob Blaustein Institutes for Desert Research, BenGurion University of the Negev, Beer-Sheva, 84990, Israel

Biofuels production as the driver of land-use change

- U.S. Energy Independence and Security Act of 2007 (EISA)
  22% of transportation fuel mix in 2022
  - 136 billion liters ethanol
    - 57 billion liters of grain-based ethanol
    - 80 billion liters of advanced ethanol (>60 cellulosic…)
- European Union
  - 20% renewable energy by 2020
  - 10% of transport fuels by 2020

Current U.S. Ethanol Production Status

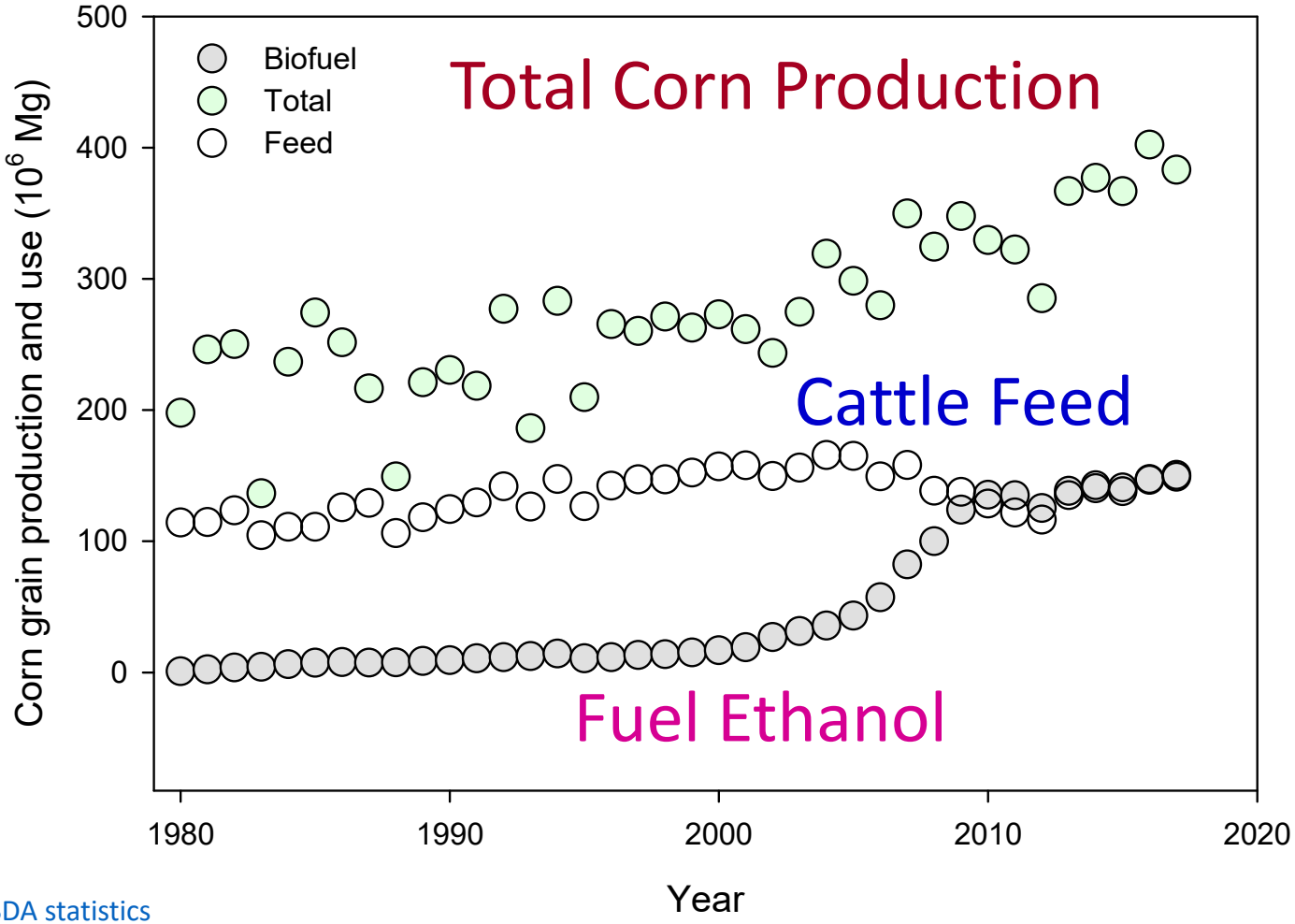
	Existing Plants	Capacity $L \times 10^9$ yr^{-1}	New Plants	Production $L \times 10^9$ yr^{-1}	Capacity $L \times 10^9$ yr^{-1}
2007	110	21	76	18	42
2008	139	30	61	24	51
2009	170	40	24	34[1]	55
2013*	204	50	2	50	56

Source: USDA 2009; DOE 2009; RFA 2010

[1] World total 66 (Brazil 24)

* ethanolrfa.org

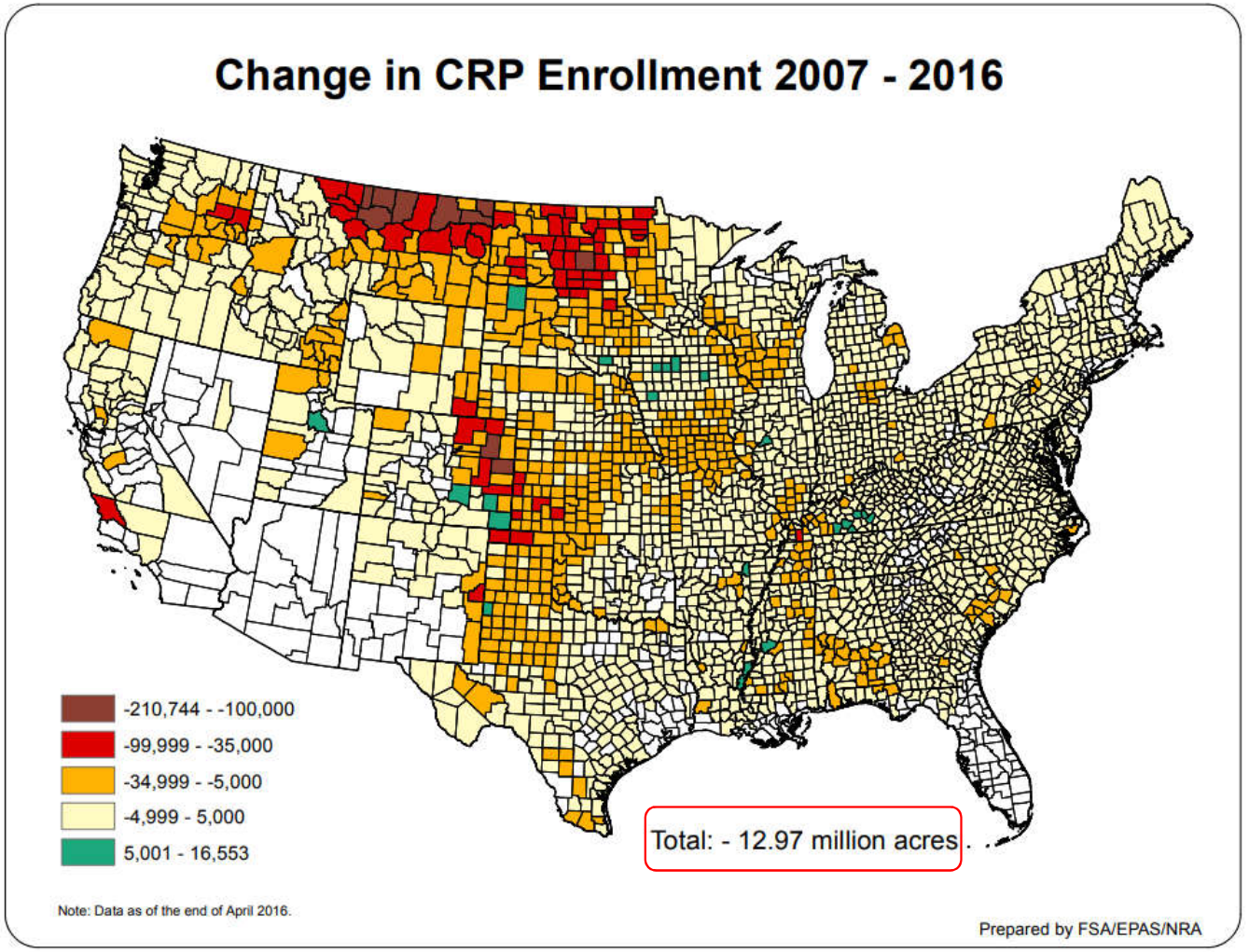
USA corn production and use



USDA statistics
www.ers.usda.gov

Land-use change from grassland to row-crop agriculture

Since U.S. Energy Independence and Security Act of 2007 (EISA) 5.5×10^6 ha of grasslands where lost to agriculture

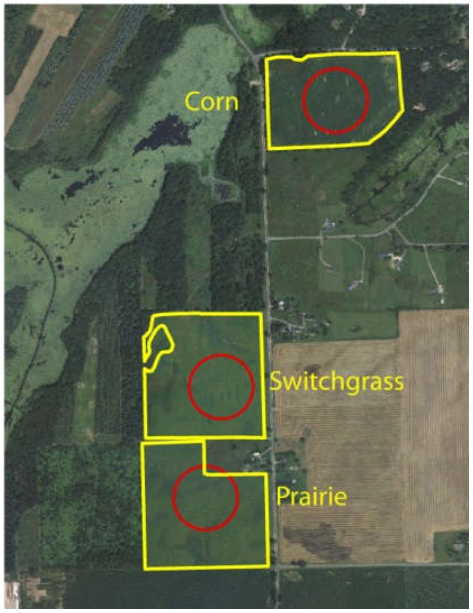


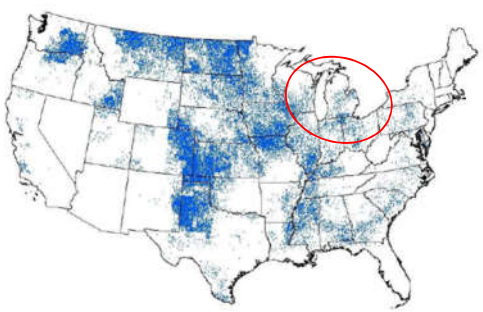
Linkages of C, N, and water cycles during land use change and management



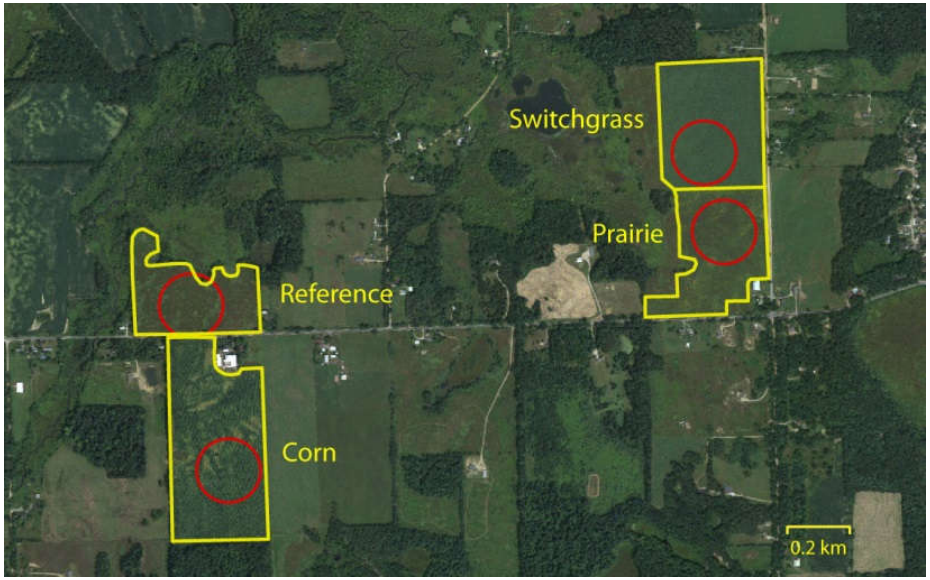



Study sites



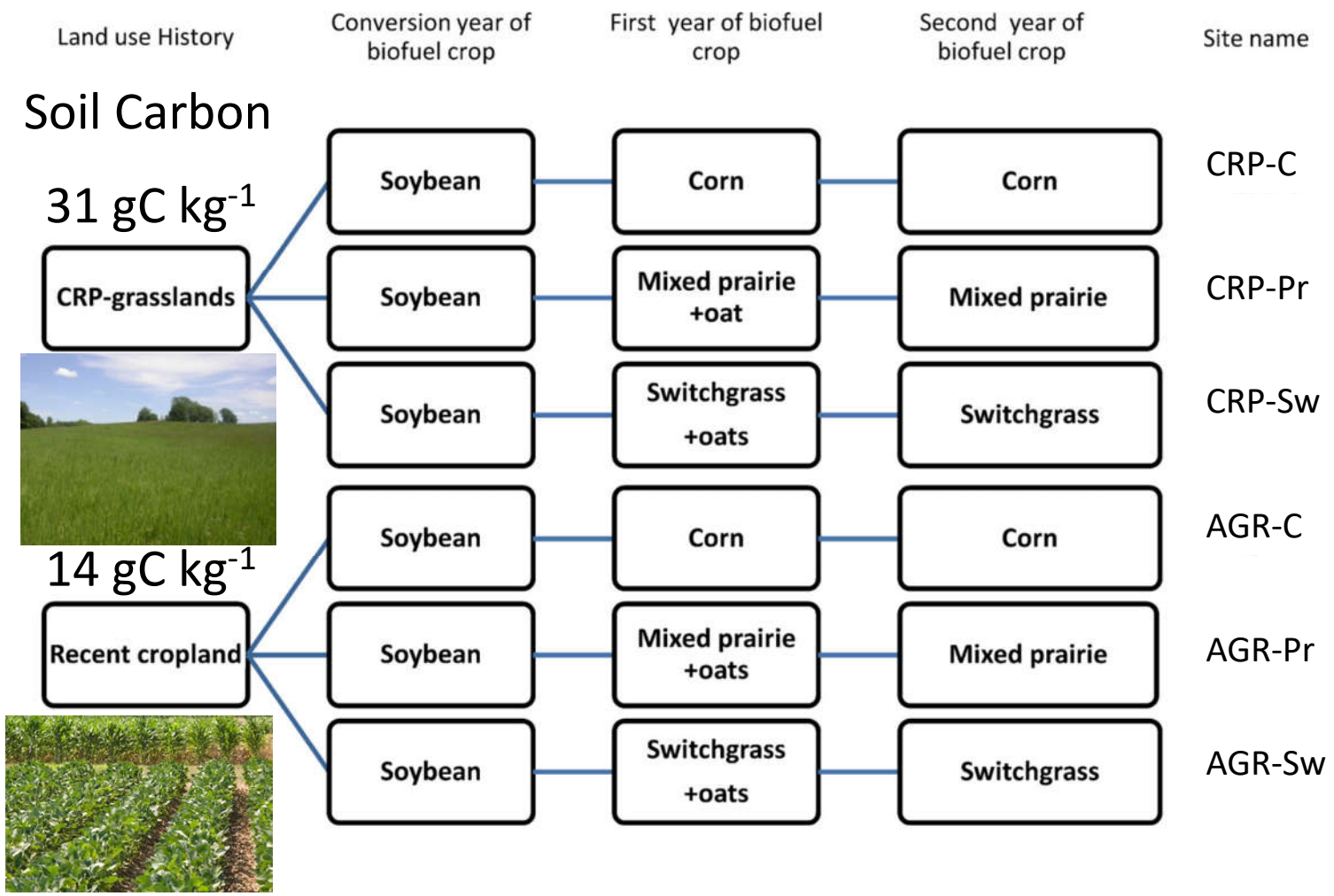


Field size: 11-17 ha
Soils: Sandy-loam
Average temperature: ~10 °C
Precipitation: ~ 1000 mm yr^{-1}



GREAT LAKES BIOENERGY RESEARCH CENTER

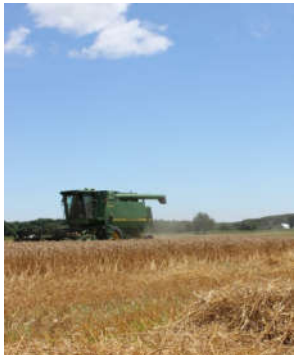
Land-use change experiment



Measurements

Eddy-covariance towers to measure ecosystem carbon balance

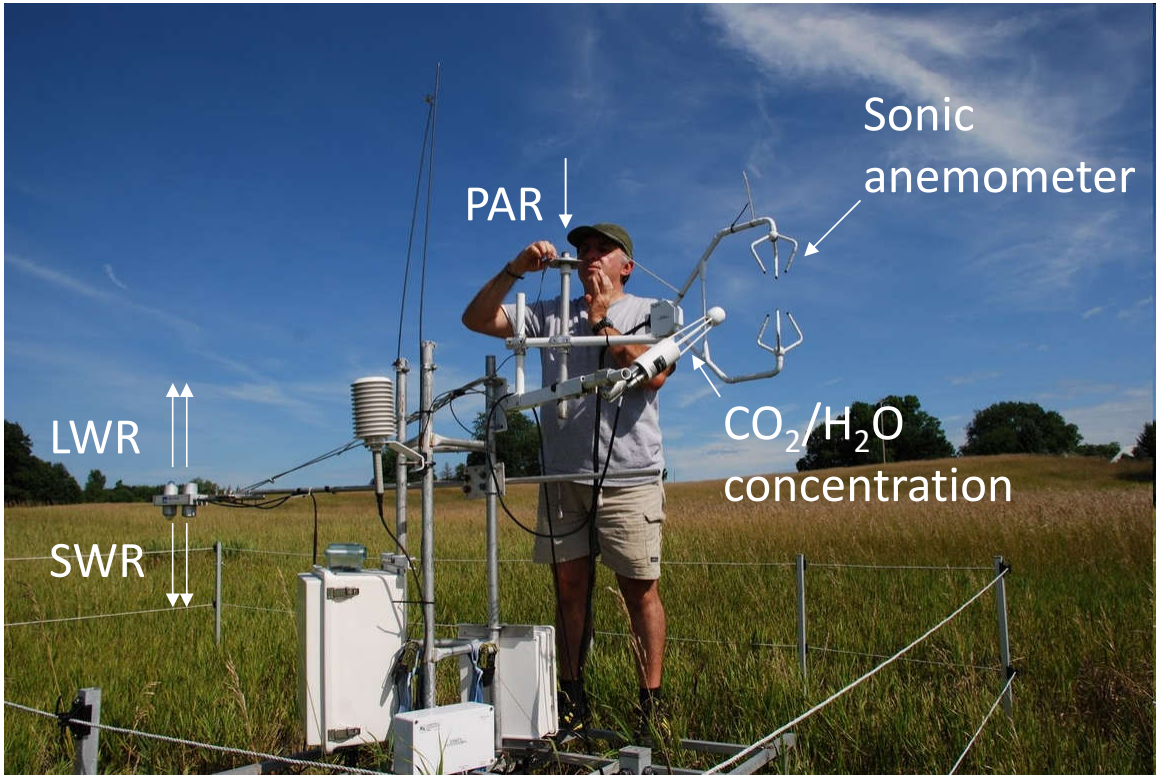
Static chambers to measure soil N_2O and CH_4 (GHG) emissions

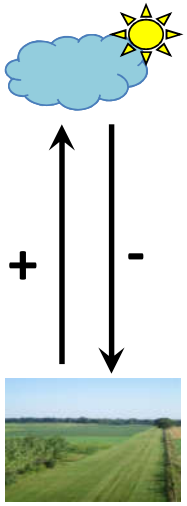


Biomass collection and harvest for species composition and productivity

Soil cores to measure soil carbon pool

Eddy-covariance tower

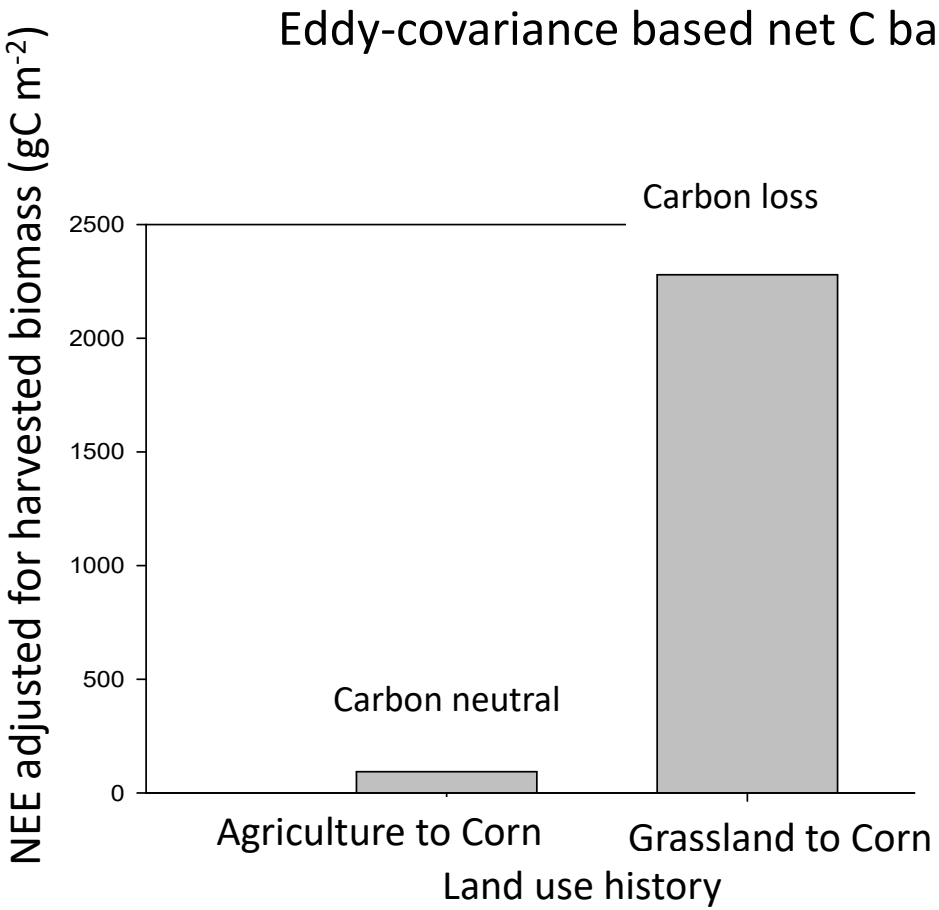


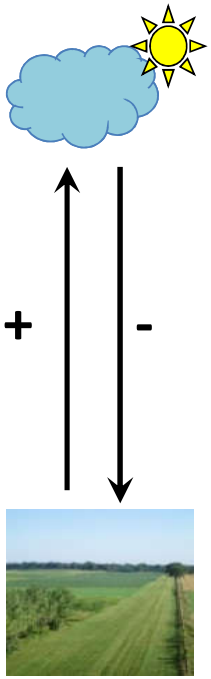


NEE = New Biomass + $\underline{\Delta SOC}$

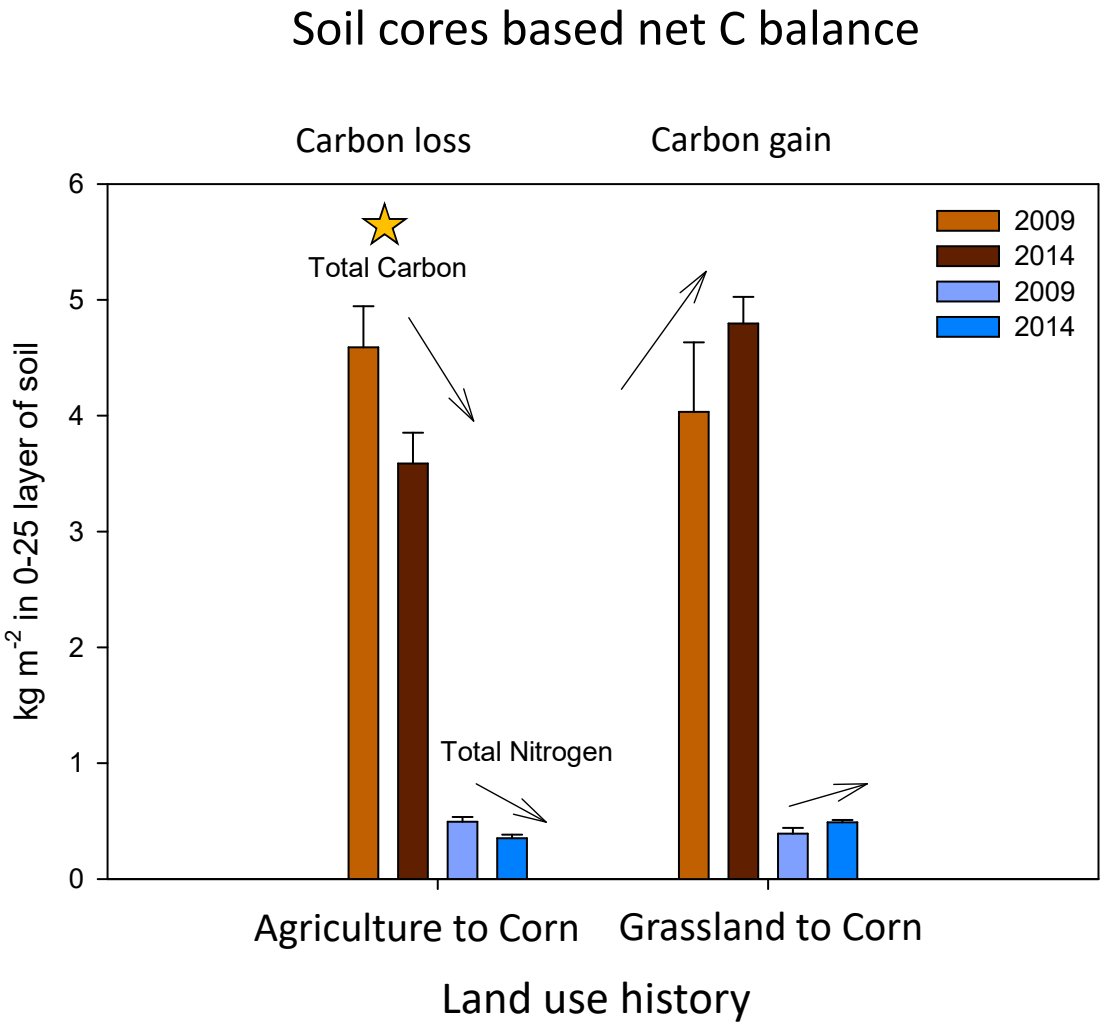
$\underline{\Delta SOC}$ = NEE – New Biomass

Soil carbon and nitrogen change

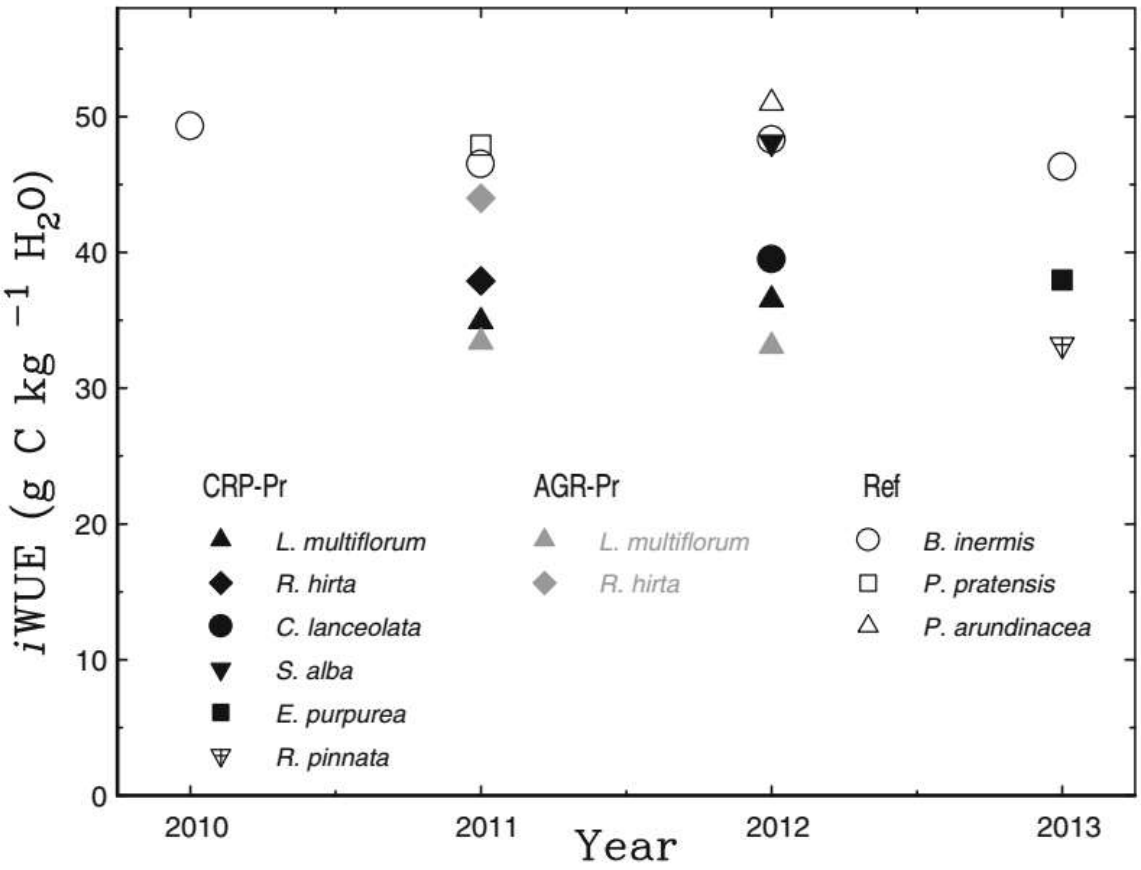




Soil carbon and nitrogen change



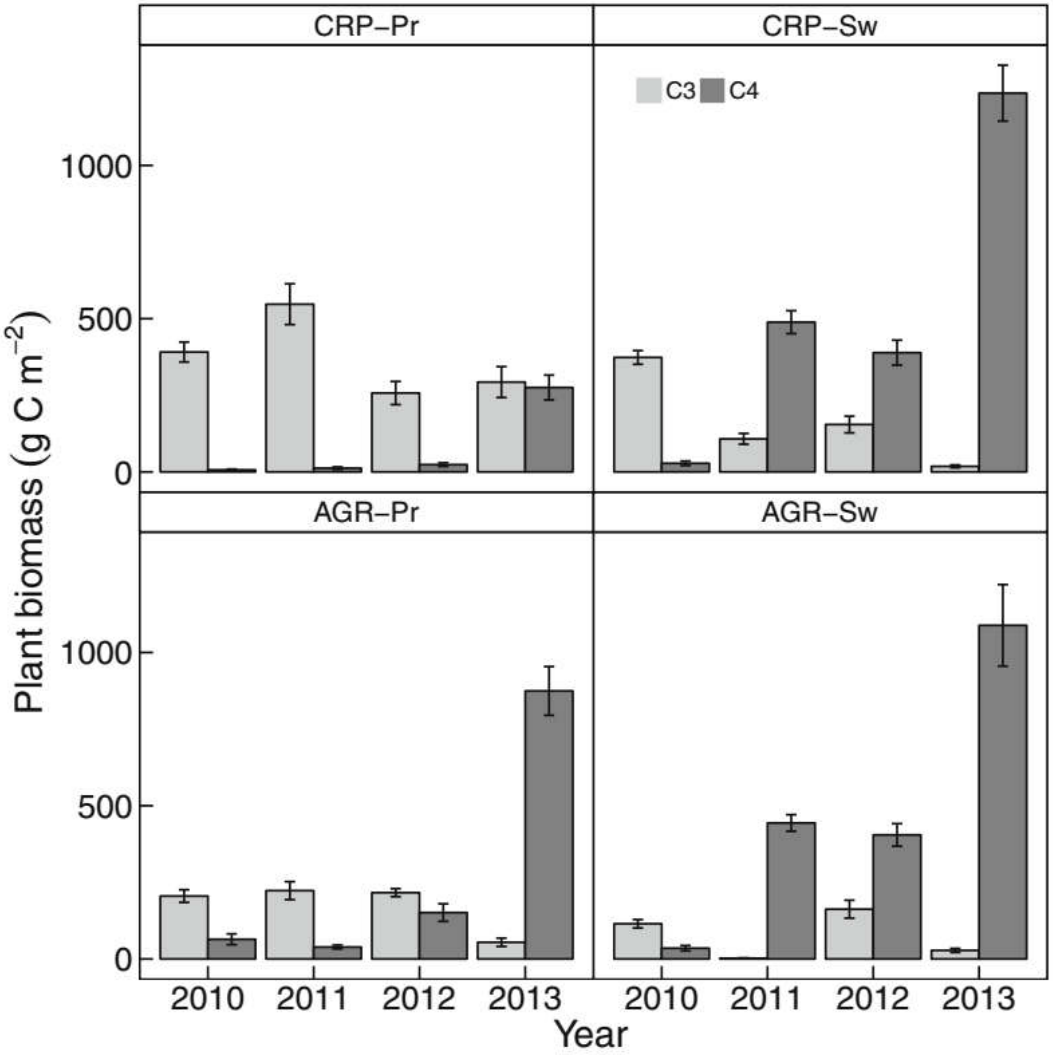
Intrinsic WUE



Abraha et al. 2016

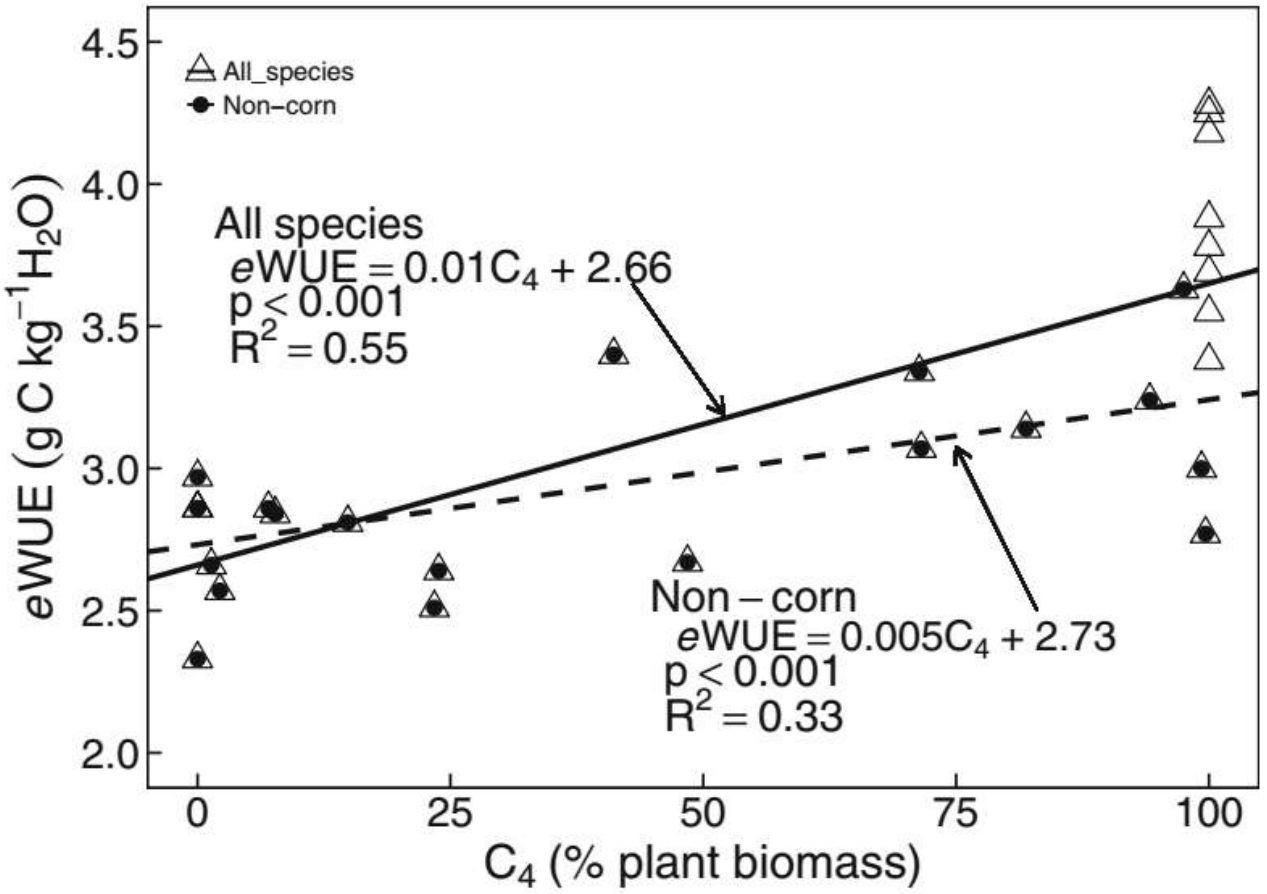
$$iWUE = \frac{A}{g_{sw}} = \frac{C_a}{1.6}\left(\frac{b' - \Delta}{b' - a}\right) \qquad \Delta = \frac{\delta^{13}C_{atm} - \delta^{13}C_{plant}}{1 + \delta^{13}C_{plant}}$$

Peak plant biomass



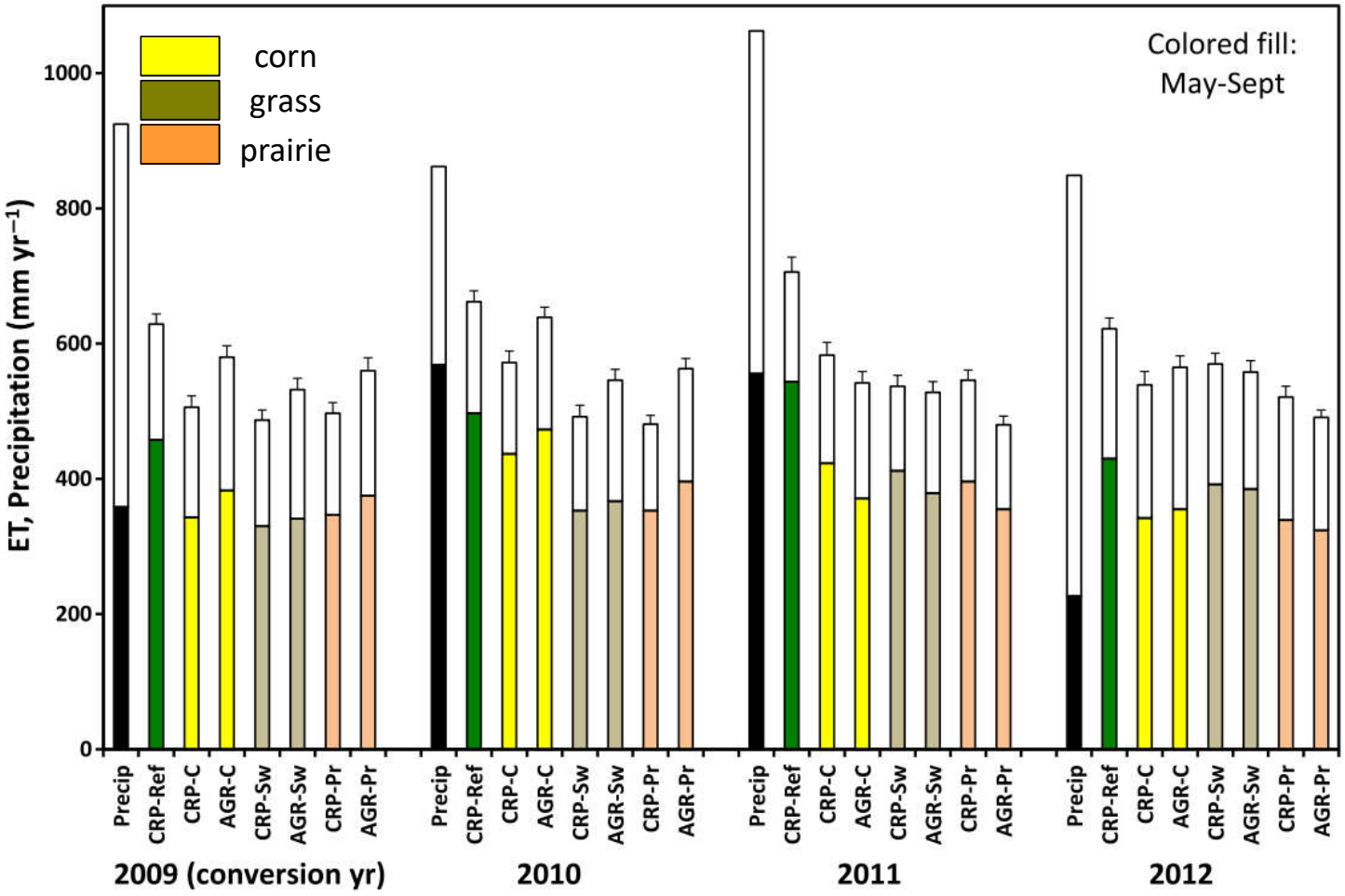
Abraha et al. 2016

Plant physiology as driver of the eWUE



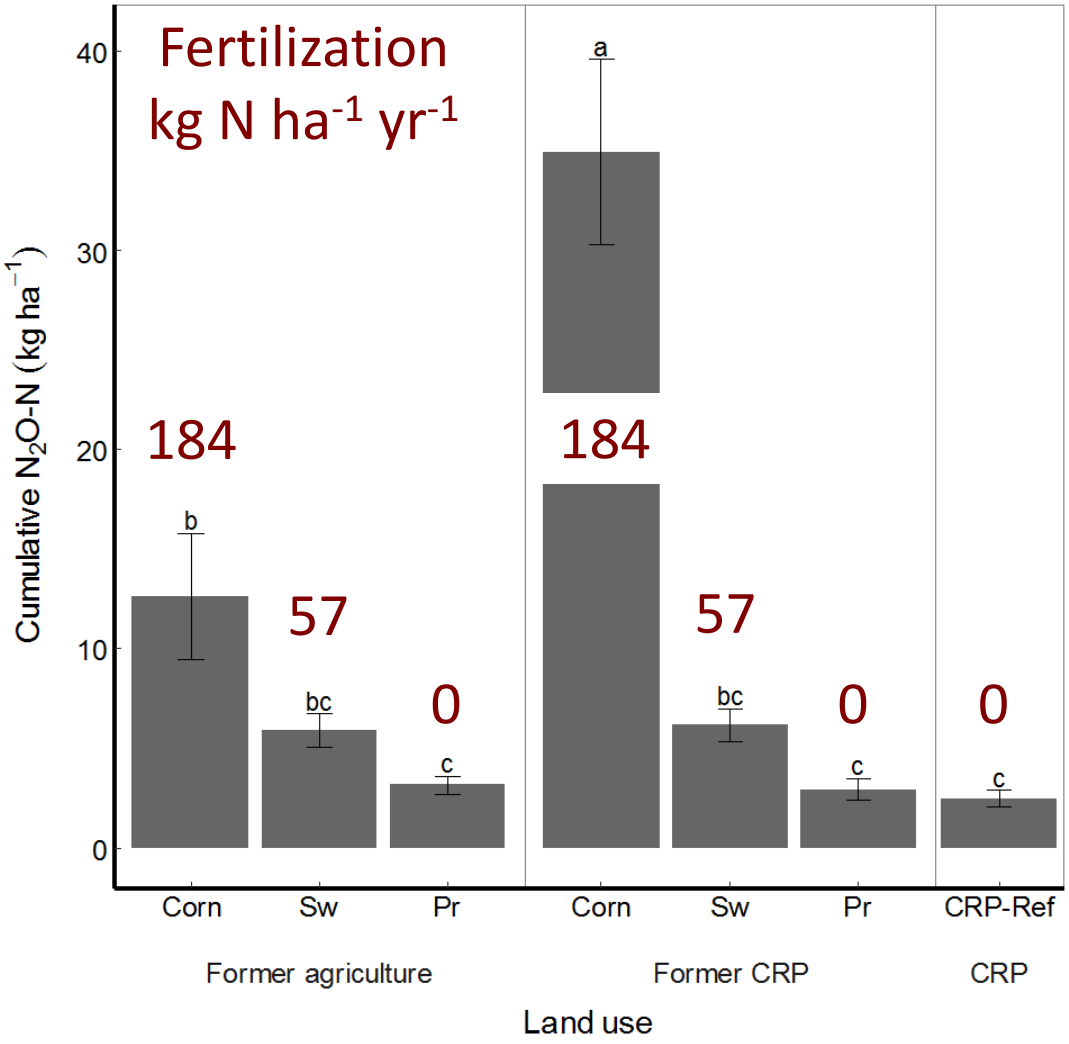
Abraha et al. 2016

ET and Precipitation of converted fields



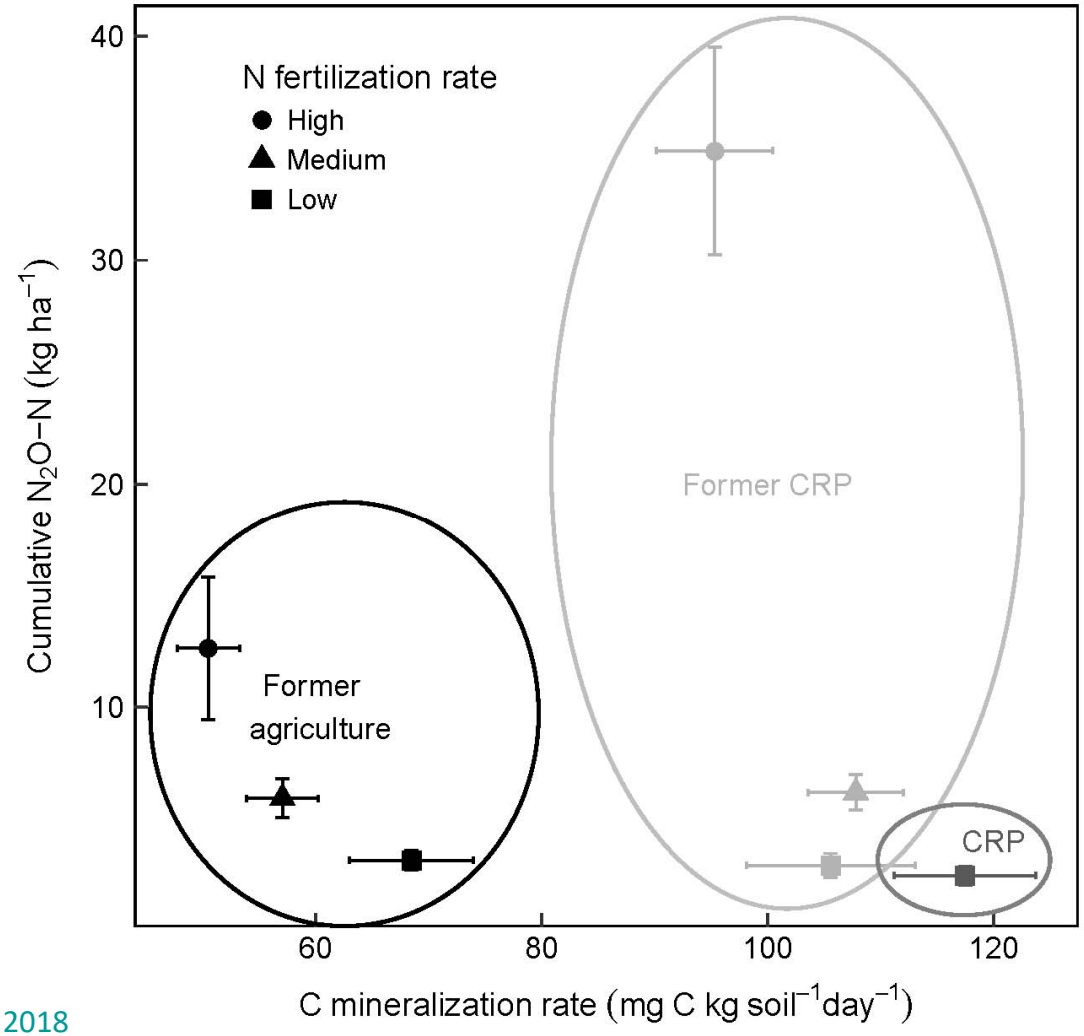
Abraha et al. 2016

Cumulative N_2O emissions



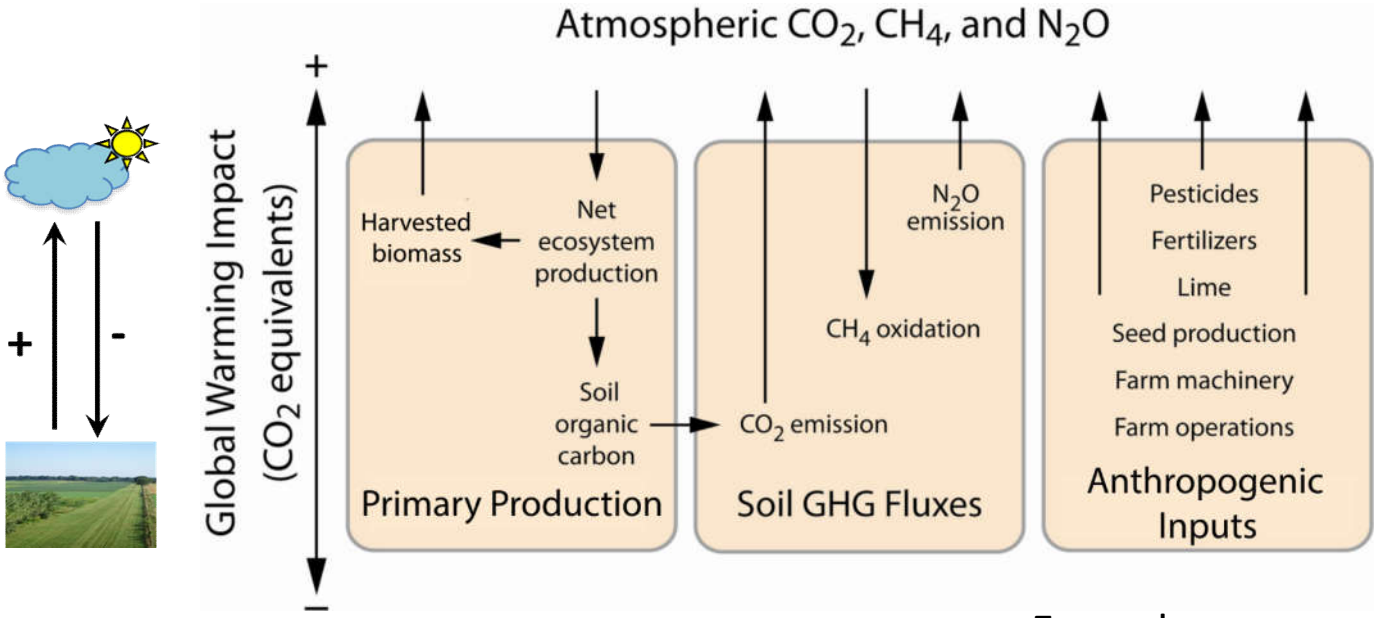
Abraha et al. 2018

The relationship between available C and soil N_2O emissions



Abraha et al. 2018

Conceptual framework to study the environmental impact of management



We use CO_2 equivalents (CO_2e) as a measure of climate impact.

CO_2e is the relative global warming impact (GWI) of a given process/greenhouse gas in units of CO_2.

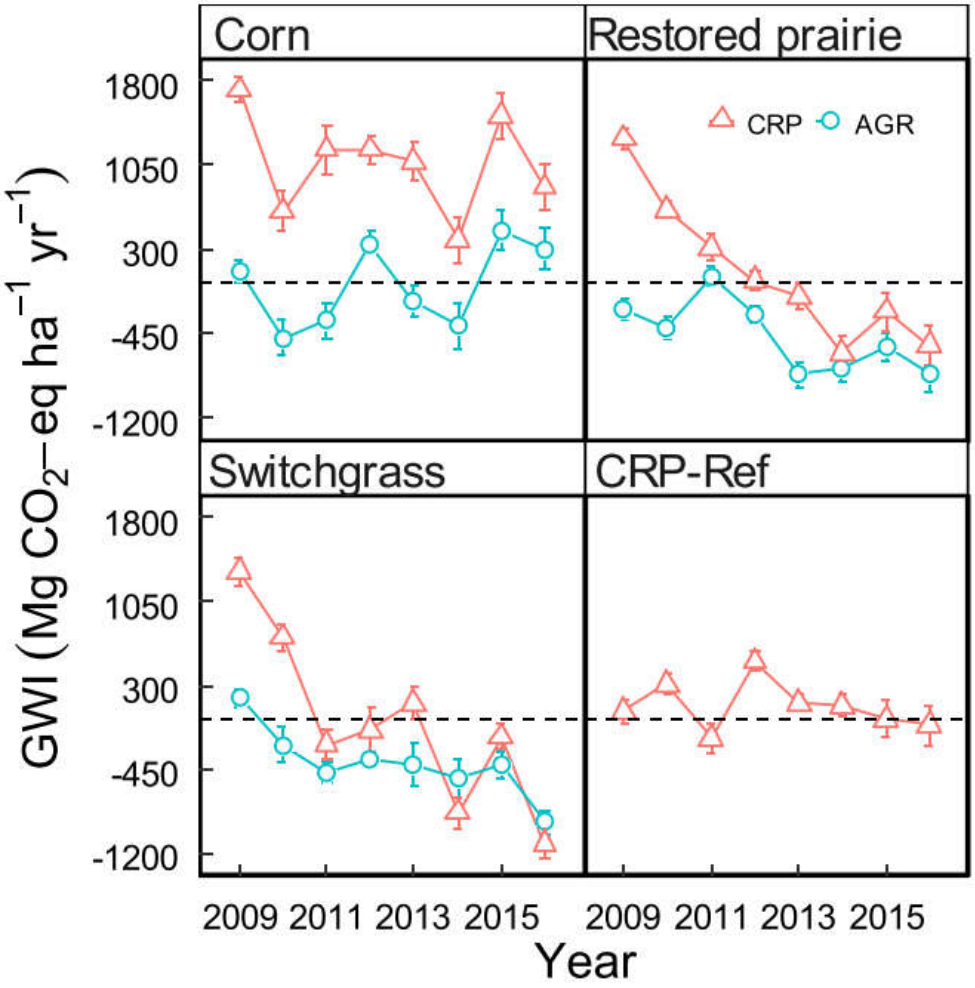
Examples:

For fertilizers:
1 kg N = 6 kg CO_2e

For greenhouse gases:
1 N_2O = 298 CO_2e

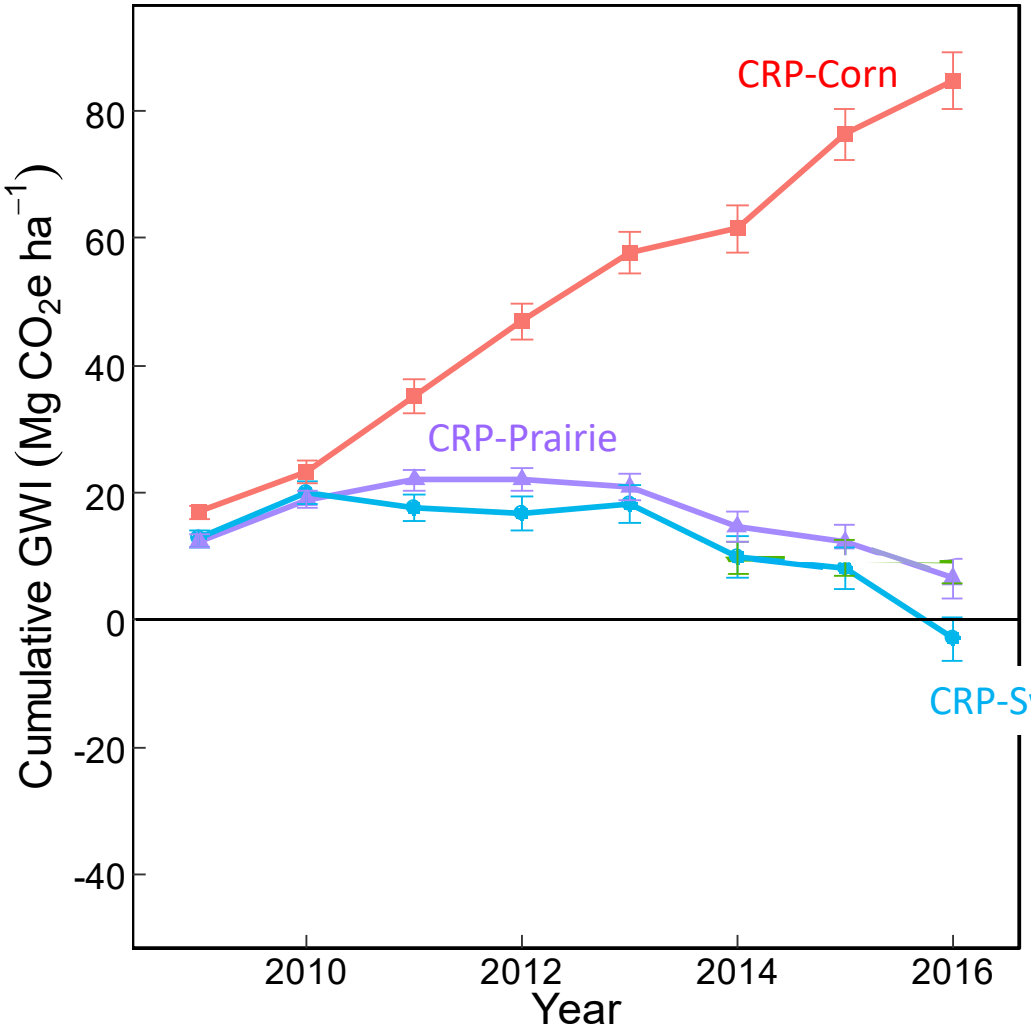
Gelfand and Robertson 2015

Global Warming Impact (temporal variation)



Abraha et al. 2019

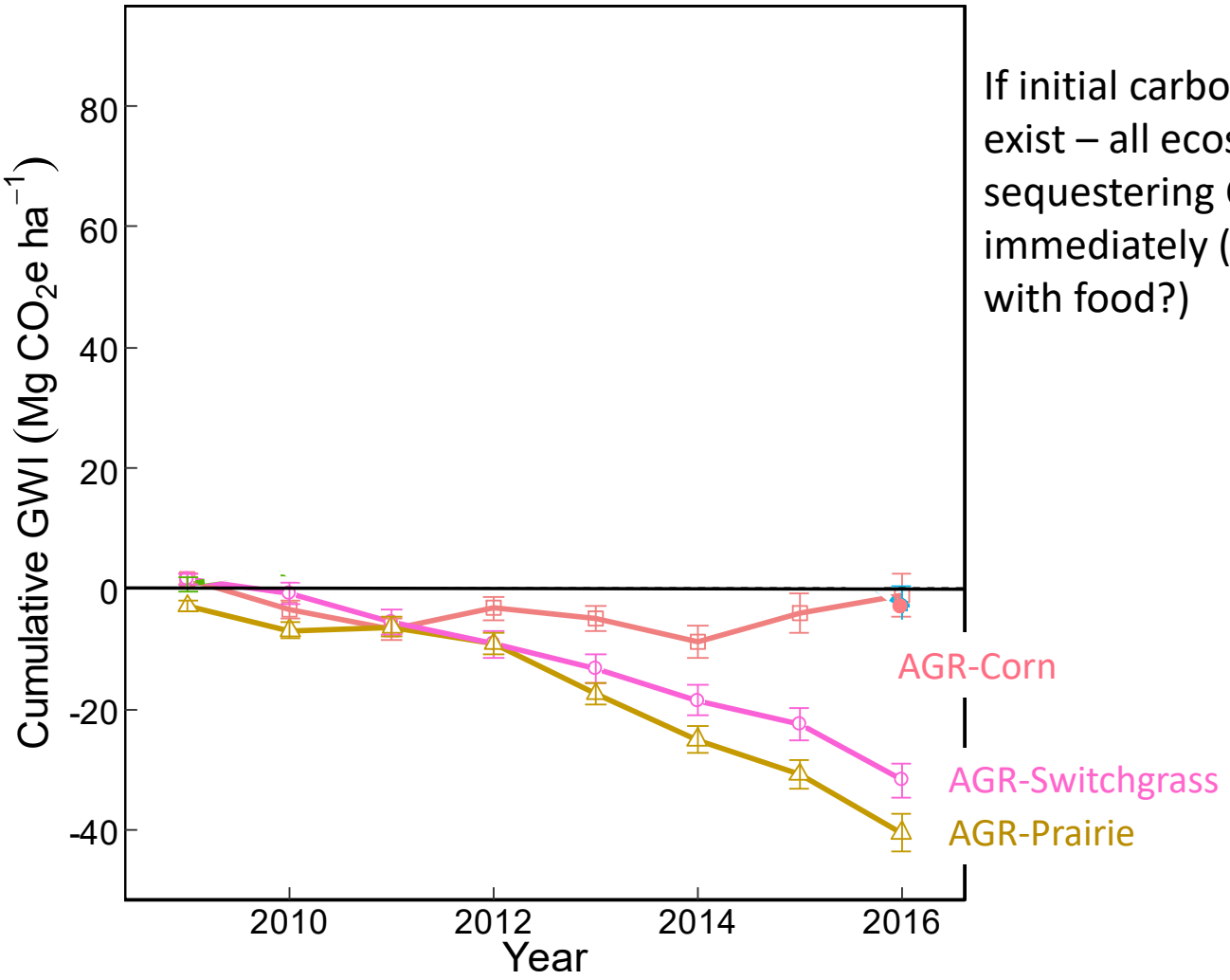
Cumulative Global Warming Impact of grassland to biofuels conversion



Within ~10 years perennial systems become neutral contrary to modeled timespan. Corn system not neutral and seems that not even close, as was predicted from models and observations.

Abraha et al. 2019

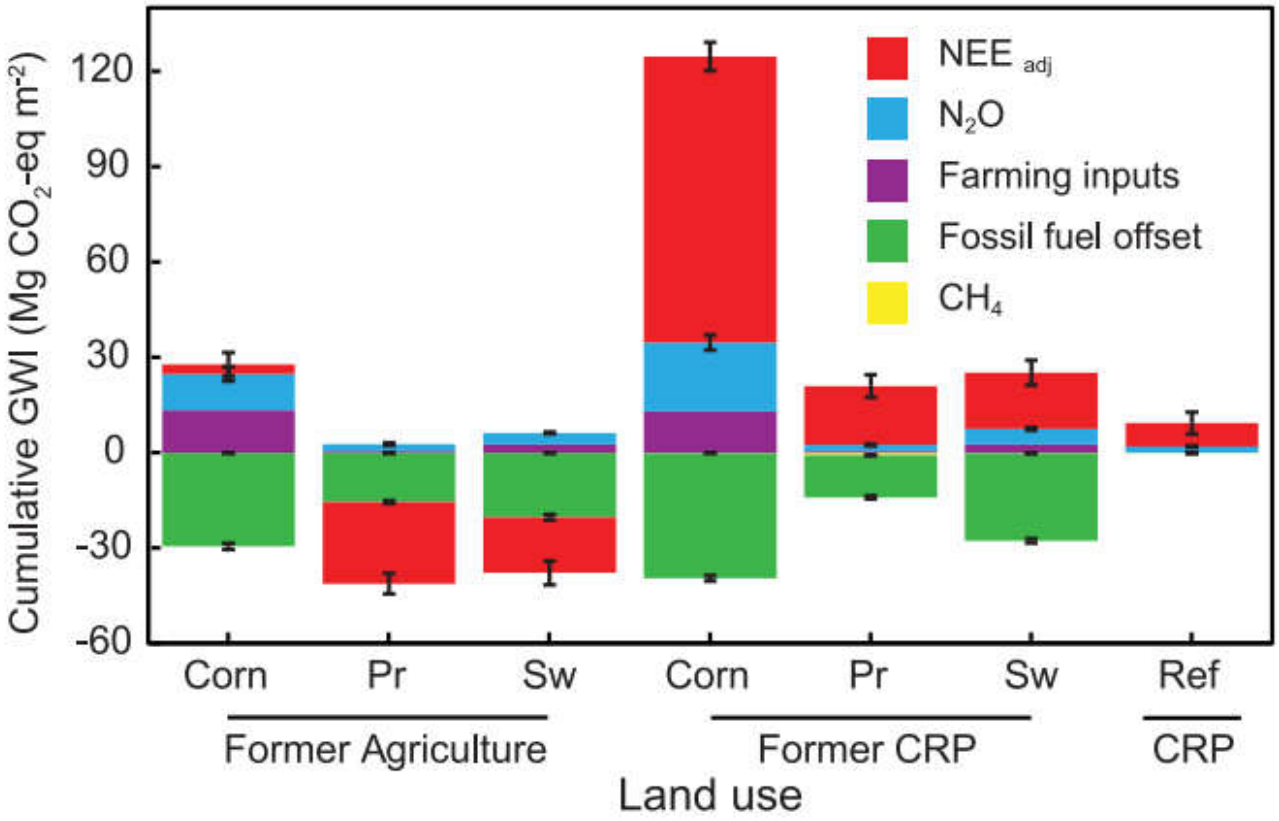
Cumulative Global Warming Impact of agriculture to biofuels conversion



If initial carbon debt is not exist – all ecosystems are sequestering C immediately (but what with food?)

Abraha et al. 2019

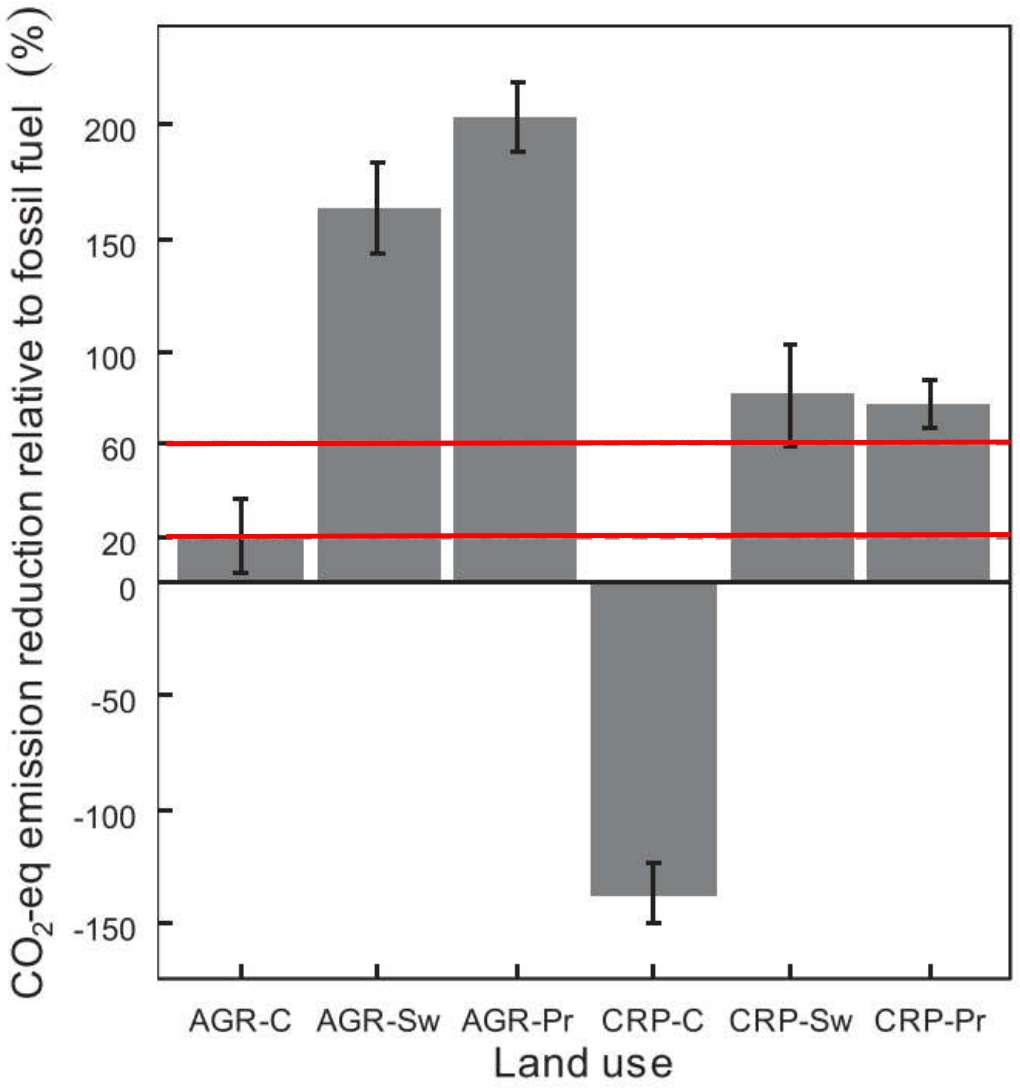
Who contributes to the global warming impact?



NEE_{adj} = Net ecosystem exchange – harvested carbon

Abraha et al. 2019

Relative CO_2e emission reduction due to use of bioethanol



Abraha et al. 2019

Conclusions

1. Land use change from grassland to agriculture and agricultural intensification causes large disequilibrium's of ecosystem C and N cycles reflected in C balance and soil N_2O emissions. The water cycle is more resilient and have not changed. Soil C plays an important role in regulation of Water and Nitrogen cycles.

2. Global warming impact of different agricultural practices is quantifiable and therefore can be managed. It’s takes between 7-8 years to forever for ecosystems to became neutral after LUC if used for lignocellulosic biofuel production.

Collaborators:

G.P. Robertson

S.K. Hamilton

J. Chen

M. G. Abraha

Field, Lab, and IT:

K. A. Kahmark

S. Bohm

C. McMinn

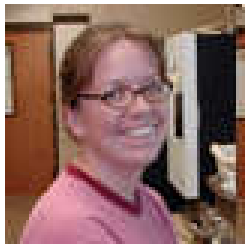
J. Simmons

S. VanderWulp










GREAT LAKES BIOENERGY RESEARCH CENTER

U.S. DEPARTMENT OF ENERGY

DOE Bioenergy Research Centers

KBS LTER

W.K. KELLOGG BIOLOGICAL STATION

NSF

BIDR The Jacob Blaustein Institutes for Desert Research