US CROPLAND EXPANSION RELEASED 115 MILLION TONS OF CARBON (2008-2012)

Summary of research presented at the America's Grasslands Conference 11/15/2017, Fort Worth, TX

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INTRODUCTION

Nearly 30,000 km^2 of cropland expansion was documented in the United States between 2008 and 2012 (Lark et al. 2015), coinciding with a period of high crop prices and new federal policies incentivizing the production of biofuel feedstocks. Cropland expansion causes a range of effects on ecosystems and the services they provide, including the release of the carbon stored in the converted natural vegetation and soils (Fargione et al. 2008, Searchinger et al. 2008, Gelfand et al. 2011). This emitted carbon re-enters the atmosphere as carbon dioxide via combustion or decomposition, thereby strengthening the greenhouse effect. Consequently, emissions from clearing land to accommodate biofuel production could significantly undermine the carbon savings that biofuels seek to attain (Gibbs et al. 2008, Elshout et al. 2015). To estimate the likely impacts of cropland expansion on natural carbon stocks and implications for biofuel efficacy, we combined high resolution maps of newly cleared croplands with spatially-explicit maps of vegetation and soil organic carbon pools. Our method, for the first time, enables us to identify specific carbon stocks effected by cropland expansion and to identify hot spots of potential C emissions.

PRELIMINARY FINDINGS

We find that cropland expansion likely resulted in carbon emissions of nearly 30 Tg yr^{-1} (SD = ± 10 Tg yr^{-1}) during the period 2008-2012 (Fig. 1). Overall, most expansion occurred throughout the Corn belt, the Great plains, and in States along the upper Great Lakes, with western New York and the central valley of California being notable exceptions (Appendix 1). The highest emissions per unit area, though, resulted from expansion in New England, States along the Eastern Seaboard and those along the Upper Great Lakes, where expansion was more likely to occur on carbon rich forests and wetlands. Taken together, these data highlight Minnesota, New York, Wisconsin, Michigan, and the Dakotas as states with the highest rates of expansion onto particularly carbon rich land. Indeed, these six states represent more than 35 percent of total annual emissions resulting from cropland expansion.

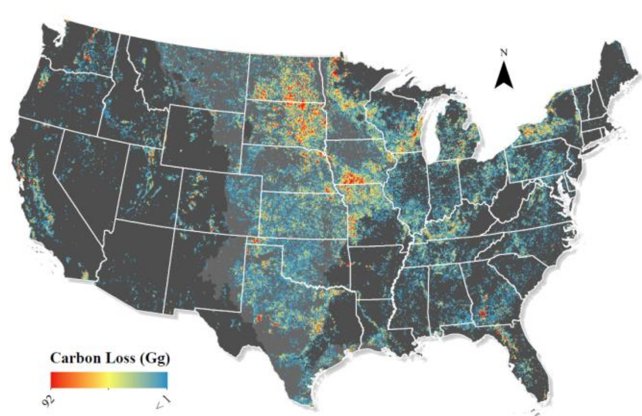

Figure 1. Potential total emissions from cropland expansion (2008-2012) estimated from initial vegetation and soil organic carbon stocks. Pixels represent aggregate sum of emissions resulting from all expansion with each 5.6 km2 grid cell.

The majority (87%) of emissions resulted from cropland expansion onto grasslands where soil carbon was the largest source of emitted carbon (Fig. 2). Expansion onto wetlands resulted in the highest potential emissions per unit area, but represented only 2% of new cropland area. Approximately 75% of all potential emissions originated from soil organic carbon pools, which take longer to both emit and restore than vegetation biomass. This implies that compensating for these carbon losses could require significantly more time than if this carbon had originated from plant matter since the mechanisms of soil carbon accumulation occur over much longer times scales (10s to 100s of years) compared to photosynthesis (1s to 10s of years).

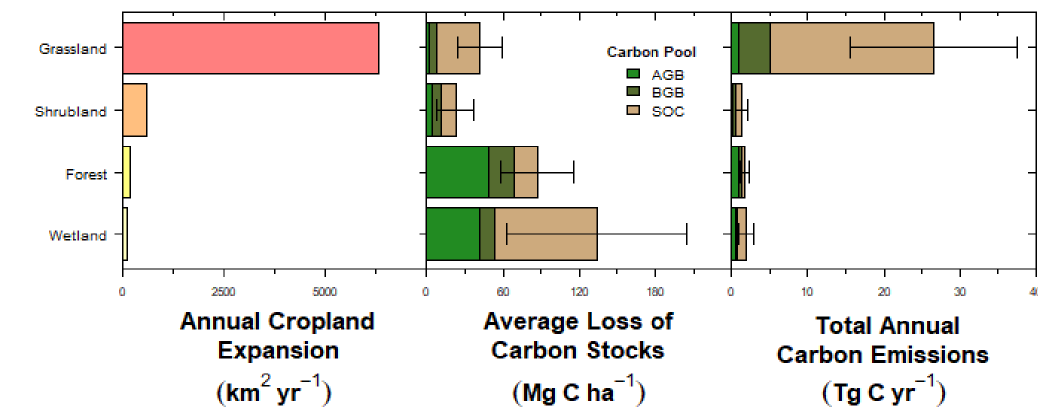

Figure 2. Annual extent of cropland expansion, average loss of carbon stocks and total annual carbon emissions from cropland expansion (2008 – 2012) by pre-cultivated land cover. Carbon loss is further stratified by the carbon pools from which emissions originated. AGB represents carbon lost from aboveground biomass, BGB represents carbon lost from below ground biomass, and SOC represents organic carbon lost from the top meter of soil.

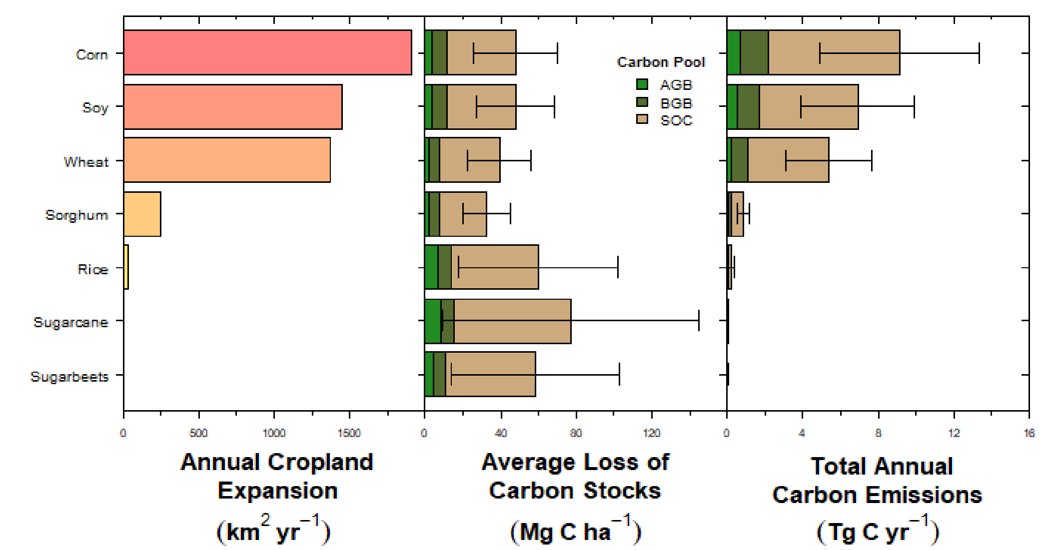

Figure 3. Annual extent of cropland expansion, average loss of carbon stocks and total annual carbon emissions from cropland expansion (2008 – 2012) for seven potential biofuel feedstock crops. Carbon loss is stratified within each crop by the carbon pools from which emissions originated. AGB represents carbon lost from aboveground biomass, BGB represents carbon lost from below ground biomass, and SOC represents organic carbon lost from the top meter of soil.

Field crops occupied the majority of newly converted land. Corn, soy, and wheat – all potential ethanol feedstocks – represented the three most prominent field crops and contributed to 85% of all potential annual emissions (Fig 3). Other potential feedstocks including sorghum, rice, sugarcane, and sugar beets also occupied new cropland but represented only a small fraction of overall expansion and emitted carbon.

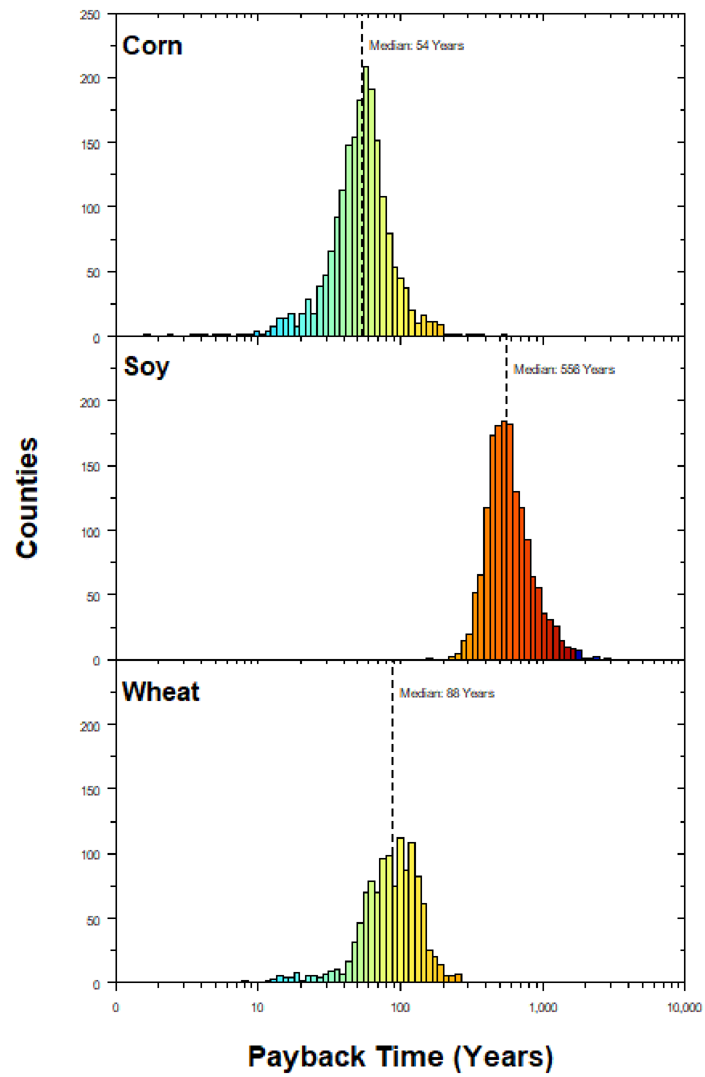

Figure 4. Ecosystem carbon payback times by county for corn, soy, and wheat grown on new cropland by county. Payback times represent the duration of biofuel feedstock production necessary to offset the initial carbon debt incurred from land conversion.

We further estimated the length of time required for the expected carbon savings of specific biofuels to offset the initial carbon debt incurred from land clearing by considering local crop-specific yields reported by USDA NASS. This analysis assumes the energy equivalence of ethanol and biodiesel to petroleum based gasoline and diesel to be 1.38 and 1.09, respectively (Gibbs et al. 2008). For corn ethanol, we predict a median payback time of 54 years, though the range is wide (1 – 300 years) due to county level differences in natural carbon stocks and corn yields. Payback times for biodiesel produced from soybeans grown on newly cleared land are significantly longer (Median: 556 years) because of the relatively low attainable fuel yields from a hectare of soybeans. Wheat is not widely used as an ethanol feedstock in the US but has been proposed as an alternative to corn when corn prices are high. We find the median payback times for wheat-based ethanol to be 88 years.

Our estimate of potential carbon emissions is 30% higher than the median estimate reported by Lark et al. (2015) though it remains within the upper range of their estimate. The approach presented here is a significant improvement because it relies on the most recent and highest resolution maps to explicitly considering the initial carbon stocks on a given piece of land. In doing so, we are able to identify hotspots of carbon emissions at the sub-county level which provides opportunities for targeted conservation and management.

METHODS SUMMARY

We combined high resolution maps of new croplands with maps of above and below ground vegetation biomass and soil organic carbon stocks to estimate the potential committed emissions of biomass and soil carbon resulting from conversion of natural land cover to cropland. Data sources used to determine carbon stocks are summarized in Appendix 2. For biomass carbon emissions, we assume complete loss of biomass carbon stocks upon conversion under the assumption that all biomass is burned (instantaneous emissions) or decomposed (prolonged emissions over 1-100 years; Houghton, 1999). For soil, we estimated potential emissions using land-cover specific emissions factors representing the proportional loss of soil carbon over time (Appendix 3; Sanderman et al. 2017, Nahlik et al. 2016), and a new, high resolution map of soil organic carbons stocks to a depth of 1m (Hengl et al. 2017). Like decomposition of plant matter, soil carbon losses occur over to course of 10s to 100s of years and our estimates should therefore be interpreted as potential 'committed' emissions.

To quantify the impacts of land clearing on biofuel carbon balance, county level carbon debt was calculated by subtracting the mean peak standing crop biomass carbon from the aggregate mean of pixel-level committed C emissions. The peak standing crop biomass carbon was estimated from mean crop- and county-specific yield data reported in the 2007 and 2012 Census of Agriculture (USDA NASS) and crop specific parameters reported in West et al. (2011). Carbon debt was then used to calculate the ecosystem carbon payback times for corn, soy and wheat following the methods of Gibbs et al. (2008) with more recent yield-to-biofuel volume relationships reported in Elshout et al. (2015).

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Appendix 1. Annual extent of gross expansion, mean carbon stock reduction and total annual carbon emissions by state

State	Annual Gross Expansion (km^2 yr^{-1})	Mean Carbon Stock Reduction (Mg ha^{-1} ± SD)	Annual Carbon Emissions (Gg yr^{-1} ± SD)
Alabama	79	37 ± 19	288 ± 153
Arizona	15	31 ± 28	47 ± 43
Arkansas	27	52 ± 43	136 ± 114
California	184	39 ± 28	724 ± 523
Colorado	214	28 ± 14	599 ± 291
Connecticut	< 1	61 ± 26	1 ± 1
Delaware	1	83 ± 55	8 ± 5
Florida	60	77 ± 52	459 ± 312
Georgia	109	56 ± 35	603 ± 380
Idaho	66	31 ± 19	207 ± 123
Illinois	135	40 ± 15	532 ± 206
Indiana	51	51 ± 27	260 ± 134
Iowa	362	44 ± 8	1600 ± 285
Kansas	438	35 ± 10	1524 ± 425
Kentucky	143	40 ± 16	573 ± 223
Louisiana	44	53 ± 44	231 ± 192
Maine	4	70 ± 27	24 ± 9
Maryland	9	47 ± 21	42 ± 18
Massachusetts	1	74 ± 41	4 ± 2
Michigan	80	87 ± 46	700 ± 370
Minnesota	263	62 ± 34	1639 ± 890
Mississippi	42	40 ± 26	165 ± 108
Missouri	413	42 ± 12	1718 ± 511
Montana	149	37 ± 14	554 ± 207
Nebraska	308	43 ± 11	1313 ± 337
Nevada	20	29 ± 28	59 ± 57
New Hampshire	1	63 ± 14	2 ± 1
New Jersey	2	55 ± 36	13 ± 8
New Mexico	84	22 ± 12	186 ± 97
New York	157	61 ± 24	960 ± 376
North Carolina	46	50 ± 51	230 ± 233
North Dakota	516	48 ± 12	2478 ± 616
Ohio	70	52 ± 22	364 ± 152
Oklahoma	275	32 ± 13	877 ± 363
Oregon	57	40 ± 30	226 ± 173
Pennsylvania	78	51 ± 22	395 ± 174
Rhode Island	0	0	0
South Carolina	8	59 ± 44	49 ± 37
South Dakota	689	47 ± 11	3262 ± 778
Tennessee	83	37 ± 21	309 ± 170

Texas	821	33 ± 14	2709 ± 1186
Utah	85	31 ± 17	262 ± 142
Vermont	7	82 ± 47	53 ± 30
Virginia	49	41 ± 19	199 ± 93
Washington	118	36 ± 25	424 ± 288
West Virginia	5	45 ± 19	21 ± 9
Wisconsin	207	61 ± 36	1256 ± 754
Wyoming	87	41 ± 25	355 ± 218

Appendix 2. Carbon datasets and models used to estimate emissions resulting from cropland expansion.

Carbon Stock	Data Used	Res.	Reference
Forests			
AGB	National Biomass Carbon Dataset (NBCD2000)	30m	Kellndorfer et al. 2012
BGB	Modeled Using:		Reich et al. 2014
	- National Biomass Carbon Dataset (NBCD2000)	30m	Kellndorfer et al. 2012
	- National Land Cover Dataset 2006 (NLCD2006)	30m	Fry et al. 2011
	- Mean Annual Temperature	800m	PRISM Climate Group
	- Frontier Forests	30m	Potapov et al. 2017
Grasslands			
AGB	Global Grassland Biomass Map	8km	Xia et al. 2014
BGB	Root-to-shoot ratios		Mokany et al. 2006
	- Koppen Climate Zones	10km	Peel et al. 2007
Shrublands			
AGB	Modeled Using:		McGinnis et al. 2010
	- Existing Vegetation Height (LANDFIRE)	30m	Wildland Fire Science
	- Existing Vegetation Cover (LANDFIRE)	30m	Wildland Fire Science
BGB	Root-to-shoot Ratio	30m	Mokany et al. 2006
Soils			
SOC	SoilGrids250v2	250m	Hengl et al. 2017

Appendix 3. Emissions factors used in conjunction with SoilGrids250v2 to estimate soil carbon emissions to a depth of 1m resulting from cropland expansion.

Initial Land Cover	Resulting Land Cover	Reduction	Source
Grassland	Cropland	26.1 %	Sanderman et al. 2017
Shrubland	Cropland	11.5 %	Sanderman et al. 2017
Forest	Cropland	13.8 %	Sanderman et al. 2017
Wetland	Cropland	42.0 %	Nahlik et al. 2016*

* Calculated as the relative difference between mean SOC stocks in the upper 1m of the 'least disturbed' and 'most disturbed' wetland categories.