Quantifying changes in soil carbon and greenhouse gas emissions from adoption of CRP

Prepared by Amy Swan, Mark Easter, and Keith Paustian of Colorado State University, for Richard Iovanna, Farm Service Agency, USDA

March 2018

1 OVERVIEW

Full results, including estimates for all emissions sources (soil carbon, soil N_2O, and woody biomass C) are provided in detail in the accompanying workbook (CRP_analysis_27Mar2018.xlsx). This report describes methods used to derive estimates and provides a general overview and discussion of results. We do not recommend generalizing results at scales not provided in the dataset (e.g. whole U.S.), without careful consideration of area-weighting.

2 APPROACH

Scenarios

Consistent with most CRP enrollments, this analysis assumes an annual cropland baseline for all scenarios. Croplands were then converted to permanent grass-dominated, grass-legume (approx. 50/50 mix), and woody cover. For all CRP cover types, we assumed no management following seeding, including no irrigation, fertilizer or other inputs, and no harvesting or grazing of aboveground biomass. Combining all baseline and conservation scenarios resulted in the following set of scenarios:

- Non-irrigated annual cropland converted to unmanaged grass-dominated CRP
- Irrigated annual cropland converted to unmanaged grass-dominated CRP
- Non-irrigated annual cropland converted to unmanaged grass-legume CRP
- Irrigated annual cropland converted to unmanaged grass-legume CRP
- Non-irrigated annual cropland converted to unmanaged woody CRP
- Irrigated annual cropland converted to unmanaged woody CRP

Soil Carbon and Soil Nitrous Oxide

Estimates of soil carbon and greenhouse gas emissions changes following conversion of cropland to CRP were generated from a sample-based, modeling approach that relied on the USDA entity-level methods guidance (Eve et al. 2014). This approach was very similar to the one used to generate estimates for the

COMET-Planner tool, as described in the accompanying report (Swan et al. 2017). Random point locations were stratified by USDA Major Land Resource Areas (MLRA) and restricted to cropland soils as defined by the USDA-NASS Cropland Data Layer (CDL) (USDA-NASS 2009-2015). We targeted a sample size of 150 points per MLRA, though MLRAs with minimal cropland land use resulted in smaller sample sizes. We extracted a cropping sequence for each point from CDL for all years available for the conterminous US. Cropping data for each point was used to build a crop rotation and determine crop-specific management such as nitrogen fertilization rates, planting dates, and harvest practices. Typical rates of N fertilizer were applied to each crop, as reported by the USDA Economic Research Service (USDA-ERS 2014). Crops were planted and harvested according to typical practices by crop and state (USDA-NASS 2010). Following long-term cropland production, CRP grasses or grass-legume mixes were planted, accounting for regional differences in dominant grass and grass-legume types (i.e. cool vs. warm season, or cool/warm season mixes). After grass and grass-legume systems were planted, no other management practices were applied.

Once we had constructed the baseline cropping and CRP scenarios, we modeled the scenarios in COMET-Farm, through an Application Programming Interface (API). The COMET-Farm API is essentially a side door into the tool that accommodates multiple runs and multiple locations without needing to enter data manually in the graphical user interface (GUI). COMET-Farm is a web-based, whole farm, GHG accounting systems that employs methods outlined in the USDA Methods for Entity-Scale Inventory guidance (Eve et al. 2014) (Figure 1).

COMET-Farm System Diagram

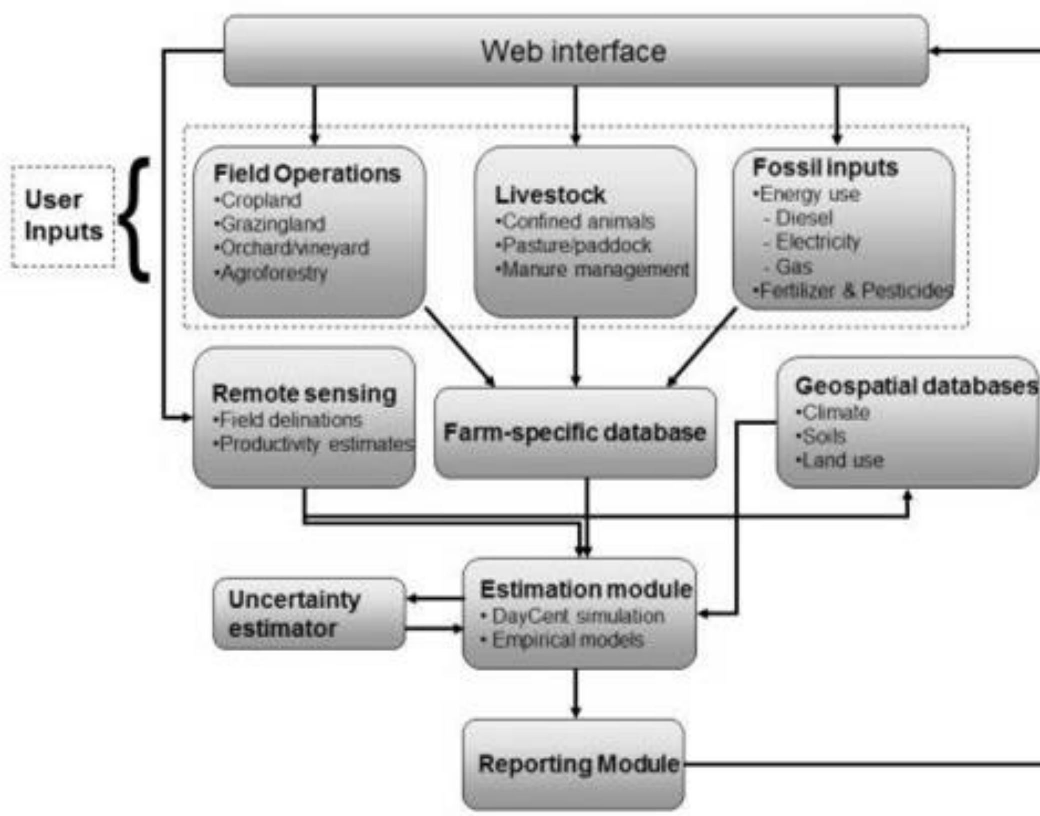

Figure 1. A diagram of the online, decision support COMET-Farm System.

Estimation methods used for most GHG sources in COMET-Farm rely on advanced methods (commonly referred to as “Tier 3” methodologies in IPCC quantification methods), such as process-based modeling in DayCent and regionally-specific empirical calculations (Table 1).

Table 1. Estimation approaches by emission source for croplands and grazing lands in the USDA Methods for Entity-Scale Inventory (Eve et al. 2014).

Table ES-1: Summary of the Sources of Emissions and Types of Approaches in this Report

Source	Basic Estimation Equation (cf., IPCC Tier 1)	Inference (cf., IPCC Tier 2)	Modified IPCC or Empirical Model (cf., IPCC Tier 2 or IPPC Tier 3)	Processed-Based Model (cf., IPPC Tier 3)
Croplands/Grazing Lands	▪ Direct N_2O Emissions from Drainage of Organic Soils ▪ CH_4 Emissions from Rice Cultivation ▪ CO_2 from Urea Fertilizer Application	▪ Soil Organic Carbon Stocks for Organic Soils ▪ CO_2 from Liming ▪ N_2O Emissions from Rice Cultivation ▪ Non-CO_2 Emissions from Biomass Burning ▪ Indirect N_2O Emissions	▪ Biomass Carbon Stock Changes ▪ CH_4 Uptake by Soils ▪ Direct N_2O Emissions from Mineral Soils	▪ Soil Organic Carbon Stocks for Mineral Soils

Outputs from COMET-Farm were processed by calculating the differences between CRP and baseline cropping scenarios for soil carbon and soil N_2O and then averaging all samples to generate a mean emission change for each scenario and MLRA. Emission changes represent 10 years since conversion of cropland to CRP, and are given in average annual emissions changes in this report. Ten years is the projection period currently used in the COMET-Farm system, however it is likely that SOC stocks will continue to change on similar trajectories under CRP beyond 10 years, barring another land use change. A prior analysis of DayCent modeled SOC change in long-term experiments predicted a rapid rate of SOC accumulation for approximately 30 years on average, after which the rate leveled off to near steady-state (Paustian et al. 2016). For the purposes of this analysis, we may assume that SOC will continue to increase in most soils for approximately 30 years on average, however the rate for years 10-30 may not be the same as for years 1-10 and we would caution against applying the change rates in this report to 30 years. Improvements are currently underway in COMET-Farm to allow flexible timelines, which would allow users to project the impacts of conservation practices over longer time periods. For some MLRAs, sample sizes were very small due to limited total annual cropland area within the MLRA. Where the sample size for a MLRA was less than 20 points, we used a Land Resource Region (LRR) average.

Woody Biomass Carbon

Models for woody biomass accumulation in agroforestry systems (windbreaks, shelterbelts, farm woodlots, silvopasture, riparian buffers and alley cropping) were built from the USDA Forest Service Forest Inventory Analysis (FIA) database, using repeated-measures data points at the individual tree species or genus level, aggregated for US Land Resource Regions (LRR). Ziegler et al. 2016 describe the method for windbreak systems, which was replicated for other agroforestry practices. The biomass accumulation models were combined with USDA/NRCS practice recommendations for the dominant agroforestry systems, projections of biomass accumulation rates for these major agroforestry installations at the LRR level were developed. As examples, biomass accumulation rates for five-row windbreaks consisting of cottonwood, eastern red cedar and green ash were modeled for the Great Plains, farm woodlots consisting of Douglas Fir were modeled for the Pacific Northwest, and mixed-species riparian buffers were modeled for the Midwest. There are 117 unique agroforestry systems modeled in the dataset, representing approximately 60 woody species, over the 26 Land Resource Regions within the conterminous U.S (Appendix 1). However, following discussions with FSA we focused the analysis for CRP on farm woodlots and riparian buffers.

3 Results and Discussion

Soil Carbon

In most MLRAs, conversion from annual cropland to either grass-dominated or grass-legume CRP resulted in SOC sequestration after 10 years (Figures 2 & 3). There are a few exceptions: in dry climates of California and the southwest, SOC declines slightly following conversion of irrigated and non-irrigated cropland to grass-dominated CRP. In these regions where both low precipitation and nitrogen availability limit plant growth, irrigation and N fertilizer inputs commonly applied in annual croplands may lead to higher plant productivity, and thus carbon inputs to soils, than permanent grasslands receiving no inputs. Field observations of SOC recovery under CRP show slow recovery in more arid climates (Munson et al. 2012) and negligible gains in sandy soils (Baer et al. 2010). Baer et al. (2010) predicted that full recovery of SOC stocks to native (pre-cultivation) levels may take over 100 years. If we extended the modeled timeframe out another 10-30 years, we may observe that SOC under CRP in these dry climates eventually surpasses that predicted under annual croplands.

The highest potential on average for SOC accumulation following CRP adoption, was converting non-irrigated cropland to grass-legume CRP (Figure 2). The potential was higher in non-irrigated cropland baseline scenarios, due to lower SOC stocks than in irrigated cropland baselines (Figure 3).

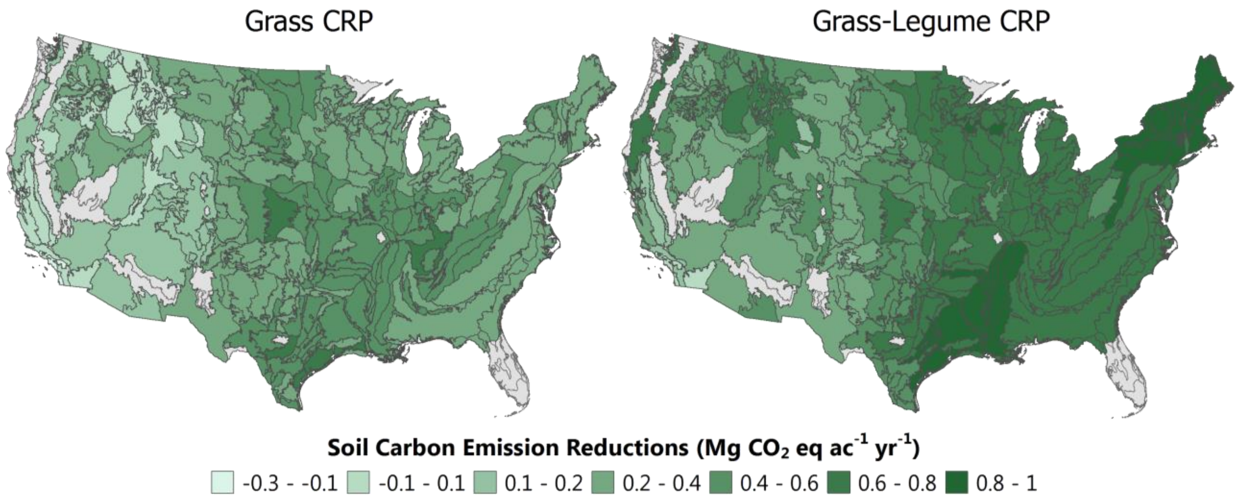

Figure 2. Average SOC emission reductions at the MLRA scale following conversion of non-irrigated cropland to grass-dominated CRP (left) and grass-legume CRP (right). Positive values indicate sequestration of carbon in soils following conversion to CRP. Regions shaded gray were not estimated due to insufficient cropland area.

In general, grass-legume CRP accumulated higher SOC stocks, than grass-dominated CRP, due to biological N fixation by legumes. However, where precipitation was a limiting factor (e.g. western Great Plains), the influence of legume N inputs was negligible, and resulted in similar SOC stocks between grass-dominated and grass-legume CRP (Figures 2 & 3).

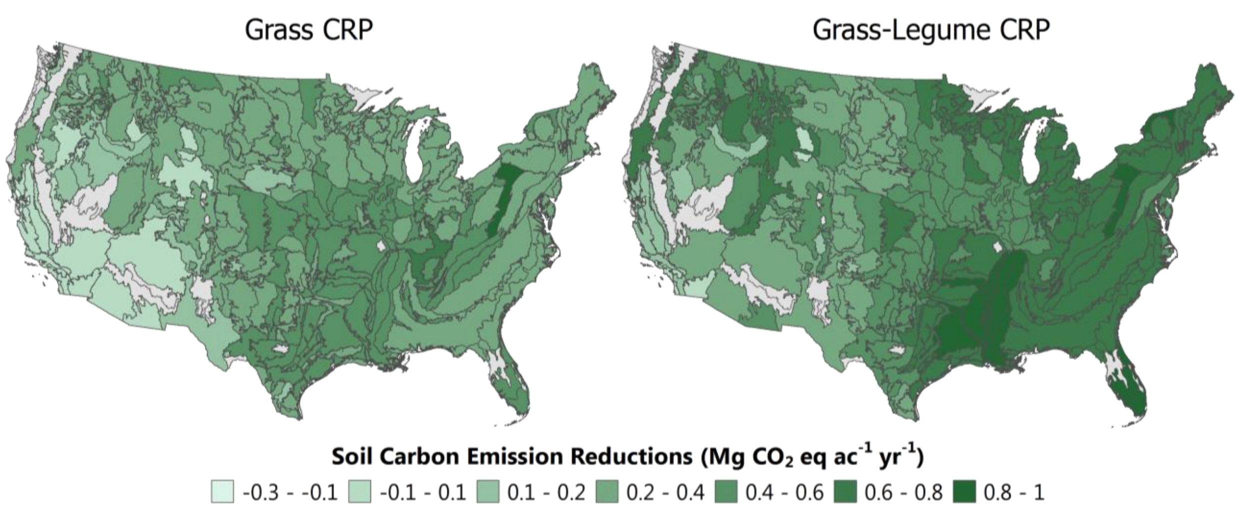

Figure 3. Average SOC emission reductions at the MLRA scale following conversion of irrigated cropland to grass-dominated CRP (left) and grass-legume CRP (right). Positive values indicate sequestration of carbon in soils following conversion to CRP. Regions shaded gray were not estimated due to insufficient cropland area.

Soil Nitrous Oxide

Annual croplands typically receive nitrogen additions in the form of synthetic N fertilizer and/or organic N amendments, such as manure. All sources of N in soils, including fertilizers, manures, plant residues, and biologically-fixed N, contribute to soil N_2O emissions via denitrification and nitrification processes. However, N fertilizer or manure additions to croplands tend to be large and cessation of those practices, as in conversion of annual cropping to permanent, unmanaged grassland, can lead to large reductions in N_2O emissions. However, the difference in N inputs between annual cropland and CRP depends on region, crop, irrigation and the plant composition and productivity of the CRP system. When converting from non-irrigated annual cropland to grass-dominated CRP, we predict nominal differences in soil N_2O emissions for most of the country (Figure 4). Non-irrigated croplands tend to receive lower N additions than irrigated croplands, due to lower crop production potential, especially in semi-arid and arid climates. For example, in non-irrigated winter wheat-fallow cropping systems, N fertilizer additions in wheat years are relatively low (30-60 lbs N ac^{-1} yr^{-1}), whereas irrigated winter wheat may receive 60-140 lbs N ac^{-1} yr^{-1} (USDA-ERS 2014). We predicted larger emissions reductions in the corn-dominated systems of the Midwest where typical fertilizer rates in non-irrigated systems range from 100-160 lbs N ac^{-1} yr^{-1} (NASS-ERS 2014). Because legumes fix atmospheric N, grass-legume CRP produced more N_2O than grass-dominated CRP (Figure 4). Due to high biologically-fixed N inputs in grass-legume systems, we predicted similar and sometimes higher N_2O emissions from grass-legume CRP than annual cropland in many parts of the country.

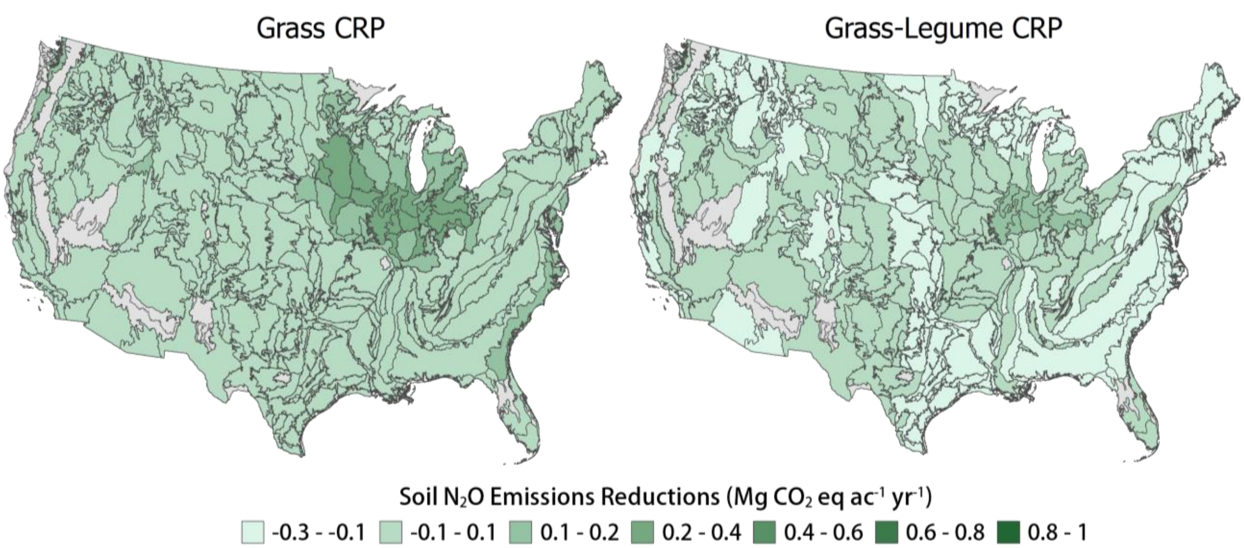

Figure 4. Average N_2O emission reductions at the MLRA scale following conversion of non-irrigated cropland to grass-dominated CRP (left) and grass-legume CRP (right). Positive values indicate reductions of N_2O emissions from soils following conversion to CRP. Regions shaded gray were not estimated due to insufficient cropland area.

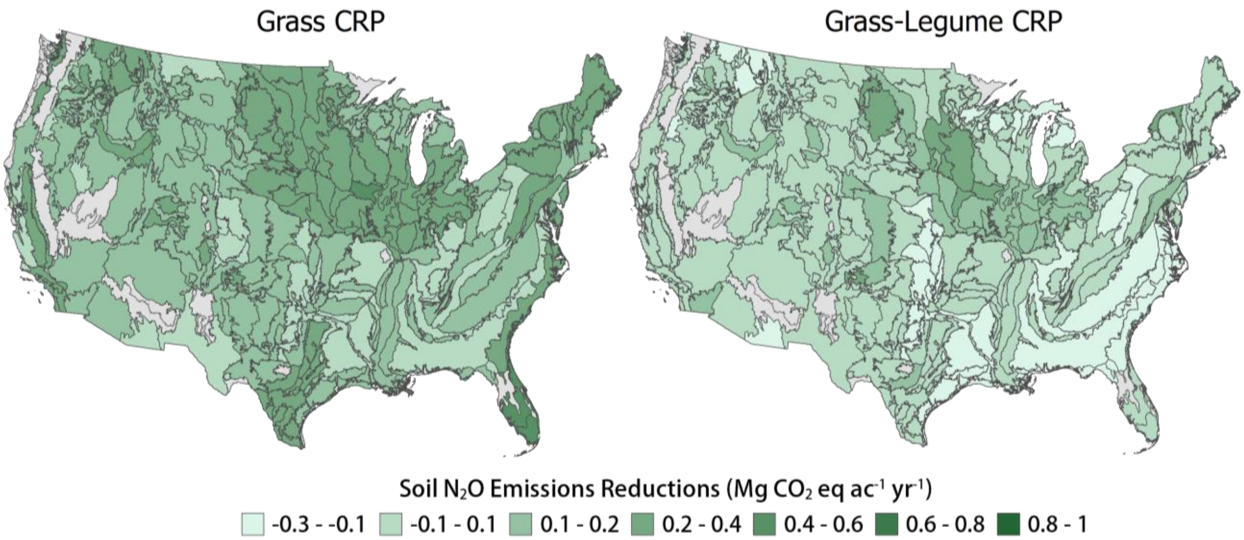

Figure 5. Average N_2O emission reductions at the MLRA scale following conversion of irrigated cropland to grass-dominated CRP (left) and grass-legume CRP (right). Positive values indicate reductions of N_2O emissions from soils following conversion to CRP. Regions shaded gray were not estimated due to insufficient cropland area.

Irrigated annual croplands generally receive higher N fertilizer applications than non-irrigated crops (USDA-ERS 2014) and wetter conditions under irrigation lead to more frequent anaerobic states resulting in N_2O emissions from denitrification (CAST 2011). As such, irrigated baseline N_2O emissions were higher than non-irrigated baseline scenarios, resulting in larger emissions reductions following conversion to both grass-dominated and grass-legume CRP (Figure 5).

Total Soil Emissions

While we did predict small N_2O emissions increases in some parts of the country following CRP adoption, when we summed SOC and N_2O emissions reductions, we found net positive emissions reductions for most MLRAs in all four scenarios. This result demonstrates why it is important to evaluate the impacts of management changes on all affected GHGs and assess the net GHG emissions impact. The highest net GHG benefits from conversion to CRP were in grass-legume CRP systems, where high C accruals offset corresponding N_2O increases (Figures 6 & 7). Divergent influences of non-irrigated and irrigated baselines on SOC and N_2O were balanced out when emission sources were summed, resulting in small differences between non-irrigated and irrigated baselines, especially in grass-legume CRP (Figures 6 & 7).

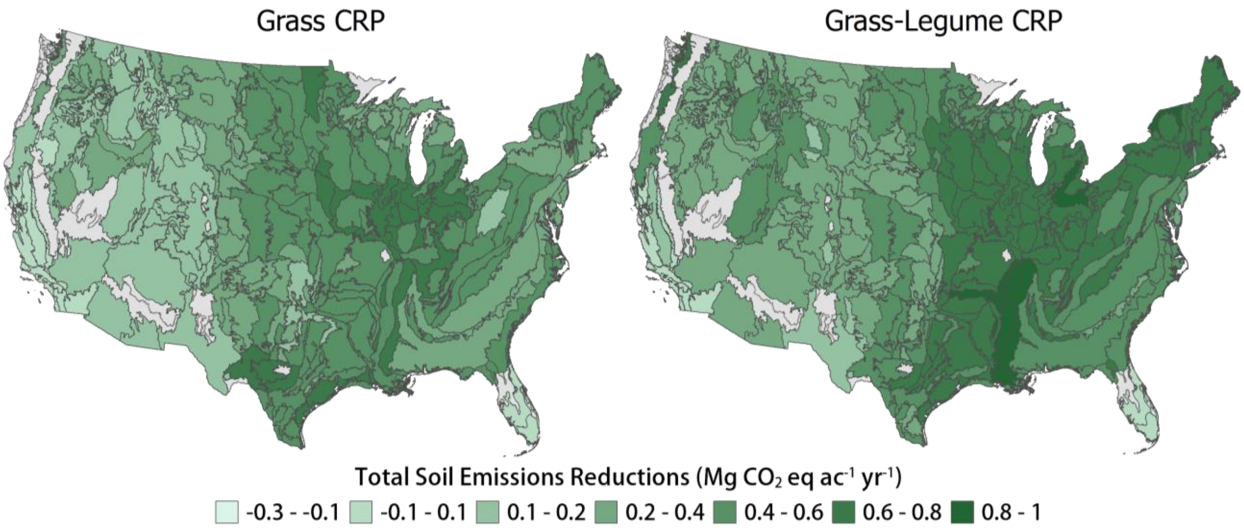

Figure 6. Average total soil emission reductions at the MLRA scale following conversion of non-irrigated cropland to grass-dominated CRP (left) and grass-legume CRP (right). Positive values indicate net emissions reductions of CO_2 and N_2O emissions from soils following conversion to CRP. Regions shaded gray were not estimated due to insufficient cropland area.

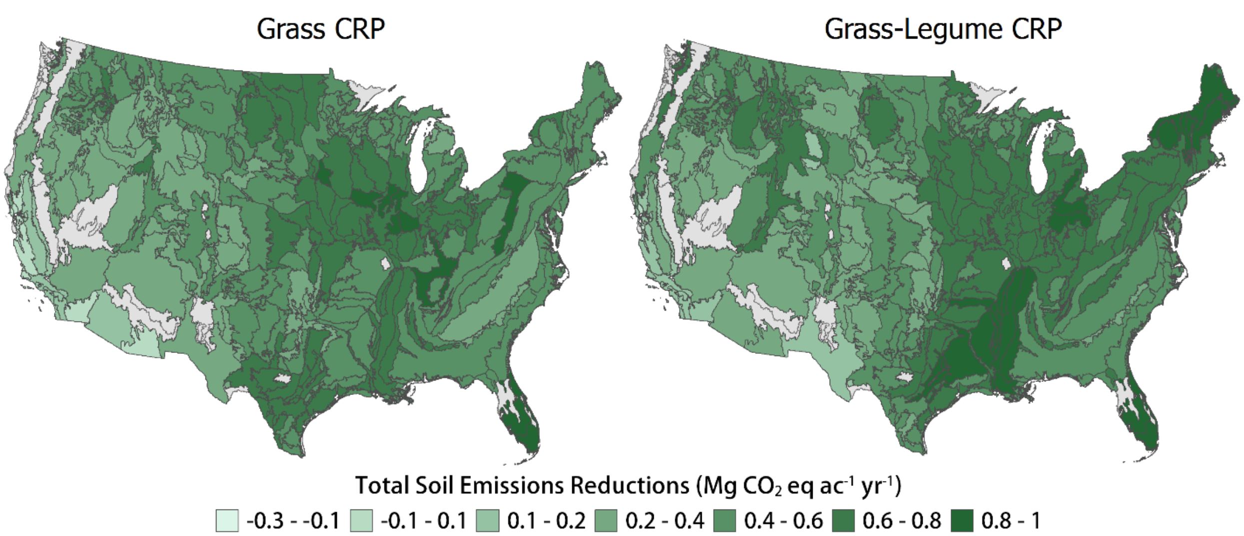

Figure 7. Average total soil emission reductions at the MLRA scale following conversion of irrigated cropland to grass-dominated CRP (left) and grass-legume CRP (right). Positive values indicate net emissions reductions of CO_2 and N_2O emissions from soils following conversion to CRP. Regions shaded gray were not estimated due to insufficient cropland area.

Woody Biomass Carbon

Scenarios of woody CRP included conversion of non-irrigated or irrigated annual cropland to farm woodlots or riparian buffers, with specific characteristics of each system varying across regions. Total woody C accumulation after 50 years varied widely across system type and region, with average accruals of approximately 50-100 Mg C ac^{-1}, and minimums as low as 9 Mg C ac^{-1} in riparian buffers and maximums as high as 247 Mg C ac^{-1} in farm woodlots (Table 2).

Table 2. Average woody biomass C accruals by agroforestry system type, 10 and 50 years after planting.

	Total (Aboveground + Belowground) Woody Biomass C Sequestration (Mg C ac^{-1})			
	10 years after planting		***50 years after planting***	
Agroforestry System	Average	Min/Max	Average	Min/Max
Farm woodlot	4.9	0.6/22.2	89.9	14.3/246.8
Riparian buffer	3.6	0.7/9.2	67.4	17.9/119.4
Riparian buffer (restored)	2.0	2.0/2.0	54.3	54.3/54.3
Riparian buffer (with black walnut and green ash)	7.0	7.0/7.0	96.1	96.1/96.1
Riparian buffer (with green ash)	2.9	0.6/7.3	48.4	9.1/75.6
Riparian buffer (without black walnut and green ash)	6.7	6.7/6.7	104.8	104.8/104.8
Riparian buffer (without green ash)	3.0	0.4/7.3	53.9	10.3/86.8

Dynamics of SOC and soil N_2O following conversion to woody cover are similar to grass-dominated CRP, and lacking a better approach to estimating impacts on SOC and N_2O in agroforestry systems, we assumed the same values as grass-dominated CRP scenarios. Using these estimates, we calculated total agroforestry system net GHG benefits after 10 years. Conversion of annual croplands to agroforestry systems led to a minimum benefit of approximately 0.2 Mg CO_2 eq ac^{-1} yr^{-1} and a maximum of 8.8 Mg CO_2 eq ac^{-1} yr^{-1}, with wide variation across regions and systems, but largely driven by woody biomass C accumulation.

4 Citations

Baer, S.G., C.K. Meyer, E.M. Bach, R.P. Klopf, and J. Six. 2010. Contrasting ecosystem recovery on two soil textures: implications for carbon mitigation and grassland conservation. Ecosphere 1(1): 1-22.

CAST. 2011. Carbon sequestration and greenhouse gas fluxes in agriculture: challenges and opportunities. Eds: R. Follet, S. Mooney, J. Morgan, and K. Paustian. Council for Agricultural Science and Technology, Ames, IA.

Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar, (Eds). 2014. Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939. Office of the Chief Economist, U.S. Department of Agriculture, Washington, DC.

Munson, S.M., W.K. Lauenroth, and I.C. Burke. 2012. Soil carbon and nitrogen recovery on semiarid Conservation Reserve Program lands. Journal of Arid Environments 79: 25-31.

Paustian, K., N. Campbell, C. Dorich, E. Marx, and A. Swan. 2016. Assessment of potential greenhouse gas mitigation from changes to crop root mass and architecture. Final report for the Advanced Research Project Agency – Energy, U.S. Dept. of Energy, Washington, D.C. Available online at : https://arpa-e.energy.gov/sites/default/files/documents/files/Revised_Final_Report_to_ARPA_Bounding_Analysis.pdf

Swan, A., M. Easter, A. Chambers, K. Brown, S. Williams, J. Creque, J. Wick, and K. Paustian. 2017. COMET-Planner: Carbon and Greenhouse Gas Evaluation for NRCS Conservation Practice Planning. Available online at: www.comet-planner.com

USDA-ERS. 2014. Agricultural Resource Management Survey (ARMS). United States Department of Agriculture, Economic Research Service, Washington D.C. Available online at: https://data.ers.usda.gov/reports.aspx?ID=17883

USDA-NASS. 2010. Field Crops: Usual Planting and Harvesting Dates, October 2010. U.S. Dept. of Agriculture, National Agricultural Statistics Service, Washington, DC. Available online at: http://usda.mannlib.cornell.edu/usda/current/planting/planting-10-29-2010.pdf>

USDA-NASS. 2009-2015. Cropland Data Layer. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/ (accessed May 2016). USDA, National Agricultural Statistics Service, Washington, DC.

Ziegler, J., M. Easter, A. Swan, J. Brandle, W. Ballesteros, G. Domke, A. Chambers, M. Eve and K. Paustian. 2016. A model for estimating windbreak carbon within COMET-Farm™. Agroforestry Systems 90: 875-887.

Appendix 1. Biomass C accumulation rates in 10 year increments for agroforestry prescriptions by LRR.

		Total (Aboveground + Belowground) Woody Biomass C Sequestration (Mg C ac^{-1})				
LRR	**Agroforestry System**	**Age: 10 years**	**Age: 20 years**	**Age: 30 years**	**Age: 40 years**	**Age: 50 years**
A	Farm woodlot	9.9	35.9	73.3	117.8	166.3
A	Riparian buffer	9.2	28.5	54.9	85.9	119.4
B	Farm woodlot	22.2	67.7	124.3	185.4	246.8
B	Riparian buffer	3.9	17.2	39.2	67.5	99.9
C	Farm woodlot	3.1	12.0	25.3	41.5	59.7
C	Riparian buffer	1.0	3.9	8.2	13.4	19.0
C	Riparian buffer (restored)	2.0	9.2	21.1	36.6	54.3
D	Farm woodlot	4.2	16.0	33.7	55.4	79.6
D	Riparian buffer	0.7	3.3	7.3	12.4	17.9
E	Farm woodlot	4.5	17.4	36.7	60.4	86.7
E	Riparian buffer	3.9	17.3	38.7	65.5	95.0
F	Farm woodlot	0.6	2.7	5.9	9.9	14.3

F	Riparian buffer (with green ash)	1.6	7.4	17.2	29.9	44.5
F	Riparian buffer (without green ash)	1.7	7.8	18.2	31.7	47.2
G	Farm woodlot	1.2	5.2	11.4	19.4	28.6
G	Riparian buffer (with green ash)	2.4	9.0	18.3	29.2	40.4
G	Riparian buffer (without green ash)	3.1	11.9	24.4	38.9	53.8
H	Farm woodlot	0.9	3.8	8.5	14.3	20.7
H	Riparian buffer (with green ash)	2.4	9.2	19.2	31.0	43.5
H	Riparian buffer (without green ash)	2.6	10.9	23.7	39.3	56.4
I	Farm woodlot	1.7	7.6	16.9	28.6	41.4
I	Riparian buffer (with green ash)	4.8	18.4	38.4	62.1	87.1
I	Riparian buffer (without green ash)	5.2	20.4	42.5	68.6	96.2
J	Riparian buffer (with green ash)	0.6	2.2	4.3	6.7	9.1
J	Riparian buffer (without green ash)	0.4	1.9	4.2	7.1	10.3
K	Farm woodlot	4.5	17.6	37.2	61.4	88.4
K	Riparian buffer (with green ash)	7.3	21.5	38.7	56.7	74.4
K	Riparian buffer (without green ash)	7.3	21.5	38.7	56.7	74.4
L	Riparian buffer	4.7	19.6	43.0	71.9	103.5
M	Riparian buffer (with black walnut and green ash)	7.0	23.9	46.5	71.3	96.1
M	Riparian buffer (without black walnut and green ash)	6.7	24.4	48.8	76.5	104.8
N	Riparian buffer	2.9	9.7	18.7	28.5	38.3
O	Riparian buffer (with green ash)	2.6	9.9	20.4	32.8	46.0
O	Riparian buffer (without green ash)	2.1	8.4	17.8	29.1	41.3
P	Riparian buffer	4.8	18.7	39.7	65.0	92.5
P	Riparian buffer (with green ash)	3.6	13.6	28.2	45.7	64.5
P	Riparian buffer (without green ash)	4.0	16.6	36.0	60.1	86.8
R	Riparian buffer	2.6	10.3	21.6	34.9	49.0

S	Riparian buffer (with green ash)	3.0	10.8	21.6	34.1	46.8
S	Riparian buffer (without green ash)	2.6	10.3	21.6	34.9	49.0
T	Farm woodlot	16.0	68.4	153.0	262.8	390.4
T	Riparian buffer	3.2	13.3	28.7	47.7	68.8
T	Riparian buffer (with green ash)	4.0	15.4	32.4	53.1	75.6
T	Riparian buffer (without green ash)	3.6	14.9	32.3	53.9	77.8
U	Farm woodlot	5.1	21.9	49.1	84.3	125.1
U	Riparian buffer	2.3	8.6	17.4	27.6	38.2