Incentives, Costs, and Implications of Wide-spread Cover Crop Adoption in the United States

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Introduction

Despite decades of research on the positive environmental impacts of cover crops, integration of cover crops into U.S. farming systems has been limited. This research explores existing obstacles to cover crop adoption as well as the potential impacts of a suite of policy mechanisms that have been proposed for overcoming those obstacles.

Cover crops are crops planted between traditional growing seasons and generally without intent to harvest. Because they are grown during a time when the soil would otherwise be bare, cover crops reduce sediment loss from runoff and salvage nutrients from the soil that might be lost to leaching during fallow periods (Dabney, Delgado, and Reeves 2001; Snapp, Swinton, Labarta, Mutch, Black, Leep, Nyiraneza, and O'Neil 2005). Cover crop biomass can also help improve soil properties and productivity by increasing organic carbon content and improving water infiltration and holding properties (Dabney, Delgado, and Reeves 2001; Sainju, Singh, Whitehead, and Wang 2006; Snapp et al. 2005). Leguminous cover crops such as clovers and Hairy Vetch provide biological nitrogen fixation, which can increase the availability of nitrogen in the soil and replace, to varying degrees, the use of Haber-Bosch nitrogen (Tonitto, David, and Drinkwater 2006).

Obstacles to cover crop adoption range from the direct costs associated with seeding and managing cover crops, to the potential for productivity losses in the cash crops that follow due to delayed soil warming and planting, residue and weed problems, reduced soil moisture, or reduced accessibility to soil nutrients (Parr, Grossman, Reberg-Horton, Brinton, and Crozier 2011; Snapp et al. 2005; Wilke and Snapp 2008). Poor access to technical resources about selection and management of cover crops and a lack of regionally adapted cover crop varieties have also been cited as a barrier to cover crop adoption (Wilke and Snapp 2008).

As a result of these and other barriers, adoption of cover crops in the United States has been limited (Singer, Nusser, and Alf 2007; Snapp et al. 2005). Singer (2007) found that in the U.S. Corn Belt, only 11% of farmers had used cover crops in the five year period from 2001 to 2005. Those farmers who did plant cover crops in the fall of 2005 planted them on only a small fraction of their land (Singer, Nusser, and Alf 2007). A number of mechanisms have been proposed, or piloted regionally, to try to stimulate cover crop adoption in the United States. This study introduces a limited set of policy options to explore the regional and national implications for cover crop adoption, as well as the net effect of subsequent changes in cropping patterns on a suite of environmental indicators.

Methodology

Regional Environmental and Agricultural Production Model

To evaluate the agri-environmental impacts of policies relevant to cover crop adoption, we use the Regional Environmental and Agricultural Production model (REAP). REAP is a national agricultural production model developed and maintained by USDA/ERS to simulate the aggregate economic impacts of farmer production decisions for 10 major commodity crops, 5 livestock sectors, and several agricultural processing sectors. The results of the REAP model are then integrated with the results of the biophysical simulation model, EPIC, to estimate the national, aggregate environmental impacts of the production patterns derived in REAP. The combined use of these tools extrapolates up from the field level to explore how field-level farmer production decisions regarding cover crop adoption translates into macroeconomic changes in price and supply of commodity crops and how/whether those changes are accompanied by changes in macro indicators of agri-environmental impacts such as aggregate nutrient loadings to surface waters, aggregate erosion levels, agricultural soil sequestration capacity, and greenhouse gas emissions from the agricultural sector.

REAP is a static, partial equilibrium model in which production, consumption and prices within the agricultural sector, as well as selected agricultural product processing sectors, are all mutually determined through complex interactions related to markets and resource constraints. The model includes 10 major commodity crops (corn, sorghum, oats, barley, wheat, rice, cotton, soybeans, hay, and silage), a number of livestock enterprises (dairy, swine, poultry, and beef cattle), and a variety of different processing technologies used to produce retail products from agricultural inputs. The data used to drive REAP are drawn from a number of national databases: the USDA production practices survey, the USDA multi-year baseline, and the National Resources Inventory.

REAP divides the United States into 45 production regions, derived from the intersection of the USDA farm production and land resource regions (Figure 1). For each of those regions, land use, crop mix, multi-year crop rotations, tillage practices and nitrogen fertilizer application rates are all endogenously determined by REAP's constrained optimization process. Each REAP region is characterized by a single representative weather pattern and two representative soils—a highly erodible soil type and a non-highly erodible soil type.

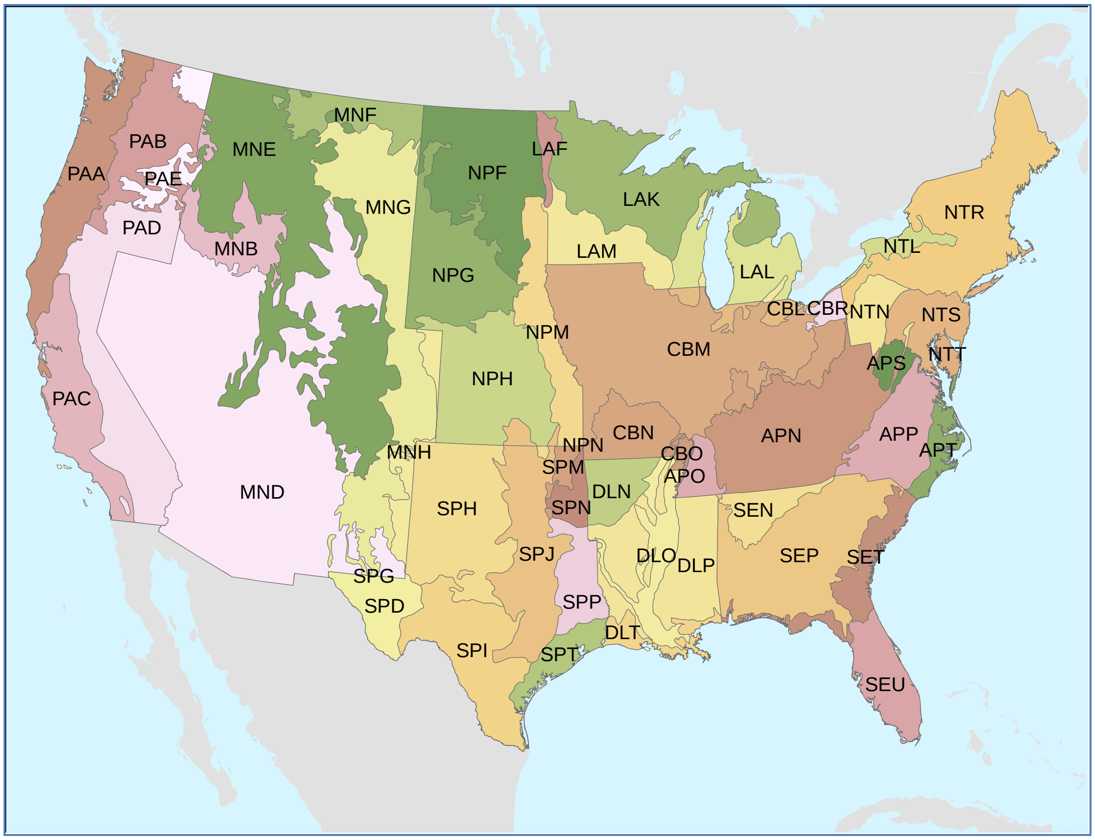


Figure 1: Crop production regions in REAP

The biophysical impacts of REAPs rotations and tillage practices are then estimated using a crop biophysical simulation model called the Erosion/Productivity Impact Calculator (EPIC). EPIC is a field-scale model that uses a daily time step to calculate the fate of various environmental parameters under different tillage, crop rotation, soil management, and weather scenarios. Although originally developed specifically to analyze the extent and costs of soil erosion, the model has been expanded over the years to simulate and provide information on hydrology, nutrient cycling, pesticide fate, soil temperature, and crop growth and yield.

REAP solves for patterns of production by selecting sets of production enterprises from among a fixed set of input enterprises, where an enterprise is defined as a particular crop rotation managed using a specified set of management practices, including tillage type, fertilizer amount, irrigation, etc. Those rotation enterprises have been run through EPIC and a production enterprise budget generator to generate yields, environmental impact parameters, and production costs associated with the specified set of crop rotation and management practices under the soil and weather conditions specified for that region. The baseline set of production enterprises included in REAP have been selected regionally using data from the National Resources Inventory to identify predominant rotations in each region.

Introducing the option for cover crop adoption requires designing a regional set of production enterprises that REAP's optimization process can select from and running those new enterprises through EPIC (to generate cash crop yield and environmental impact information) and a crop budget generator

(CBG) (to generate cost of production information for rotations incorporating cover crops). To maintain comparability across enterprises, EPIC biophysical parameters and the CBG farm budget parameters were held constant across the traditional and the new "alternative" versions of those enterprises that incorporated cover crops into one or more years of the rotation.

The effort to design a comprehensive set of production enterprises that incorporate region-appropriate cover crops into all or a fraction of their rotation years began by identifying the predominant rotation enterprises in each region (Table 1). All non-perennial (i.e. non-hay) rotations were considered eligible rotations for the addition of a cover crop. In addition to the rotations shown in Table 1, a handful of other rotations that had been identified in prior research by the World Resources Institute as candidate rotations for cover were included in the final list of cover-crop enhanced production enterprises (Table 2).

Table 1: Rotations with the greatest amount of acreage in each REAP region.

REAP Region	Farm Production Region	Major Rotations	Legend
APN	App.	RCB, RHHH,	RBBB= Continuous Soybean
APP	App.	RCB, RBBB, RHHH, RTTT	RBR= Soybean/Rice
APS	App.	RCCC, RHHH	RBWS= Soybean/Wheat/Sorghum
APT	App.	RCB	RCB= Corn/Soybean
CBL	Corn Belt	RCB, RCBW	RCBW= Corn/Soybean/Wheat
CBM	Corn Belt	RCB	RCCC= Continuous Corn
CBN	Corn Belt	RCB, RHHH	RHHH= Continuous Hay
CBO	Corn Belt	RBBB, RCB. RTTT	RRRR= Continuous Rice
CBR	Corn Belt	RCB, RHHH	RSSS= Continuous Sorghum
DLN	Delta	RBBB	RST= Sorghum/Cotton
DLO	Delta	RBBB, RBR, RTTT	RTTT= Continuous Cotton
DLP	Delta	RBBB, RBR, RTTT	RWF= Wheat/Fallow
DLT	Delta	RBR, RRRR	RWL= Wheat/Barley
LAF	Lake	RBW, RWWW, RWL	RWWW= Continuous Wheat
LAK	Lake	RCB, RCCC, RCH	
LAL	Lake	RCB, RCCC,	
LAM	Lake	RCB	
MNB	Mountain	RHHH, RWL, RWF, RWWW	
MND	Mountain	RHHH, RWF	
MNE	Mountain	RHHH, RWF, RTTT	
MNF	Mountain	RHHH, RWF, RWWW	
MNG	Mountain	RHHH, RWF, RWWW	
MNH	Mountain	RWF, RWWW	
NPF	N. Plains	RBW, RCW, RHHH, RWF, RWL,	
NPG	N. Plains	RHHH, RWF	
NPH	N. Plains	RWF, RCCC, RCB	
NPM	N. Plains	RCB	
NTL	North East	RHHH	
NTN	North East	RHHH	
NTR	North East	RHHH	
NTS	North East	RHHH, RCB, RCCC, RCH	
NTT	North East	RCB	
PAA	Pacific	RHHH	
PAB	Pacific	RWF	
PAC	Pacific	RHHH, RTTT, RRRR	
PAD	Pacific	RHHH	
PAE	Pacific	RHHH	

SPH	S. Plains	RTTT, RWF. RWSF, RWWW	
SPI	S. Plains	RSSS. RST	
SPJ	S. Plains	RSSS. RWWW	
SPM	S. Plains	RBWS, RCB, RHHH	
SPP	S. Plains	RHHH	
SPT	S. Plains	SRST	
STN	SouthEast	RBBB	
STP	SouthEast	RTTT, RBBB, RCCC	
STT	SouthEast	RCB	

Table 2: Rotations designed with cover crops integrated into one or more years of the rotation.

USMP Region	Rotations Created
APN	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch
APP	Corn/Soybean/Hairy Vetch
APS	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch
APT	Corn/Soybean/Hairy Vetch
CBL	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Continuous Corn/Red Clover; Corn/Soybean/Red Clover
CBM	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Continuous Corn/Red Clover; Corn/Soybean/Red Clover
CBN	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Continuous Corn/Red Clover; Corn/Soybean/Red Clover
CBO	Continuous Corn/Hairy Vetch; Soybean/Wheat/Red Clover; Continuous Soybean/Rye; Continuous Corn/Red Clover
CBR	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Continuous Corn/Red Clover
DLN	Continuous Soybean/Rye; Continuous Soybean/Crimson Clover
DLO	Continuous Cotton/Crimson Clover; Corn/Soybean/Crimson Clover; Continuous Soybean/Rye; Continuous Soybean/Crimson Clover
DLP	Continuous Cotton/Crimson Clover; Continuous Corn/Hairy Vetch; Continuous Rice/Subterranean Clover; Corn/Soybean/Subterranean Clover
DLT	None
LAF	Soybean/Wheat/Rye; Wheat/Barley/Hairy Vetch; Wheat/Red Clover
LAK	Continuous Corn/Rye; Corn/Soybean/Rye
LAL	Continuous Corn/Rye; Corn/Soybean/Rye
LAM	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Continuous Corn/Red Clover; Corn/Soybean/Red Clover
MNB	Wheat/Rye
MND	Continuous Corn/Hairy Vetch; Continuous Cotton/Crimson Clover
MNE	Wheat/Rye
MNF	Wheat/Rye
MNG	Wheat/Rye
MNH	Wheat/Rye; Wheat/Field Peas; Continuous Corn/Hairy Vetch;
NPF	Wheat/Sweet Clover; Continuous Corn/Hairy Vetch; Continuous Corn/Red Clover; Continuous Corn/Rye
NPG	Continuous Corn/Hairy Vetch; Wheat/Rye; Continuous Corn/Red Clover; Continuous Corn/Rye
NPH	Continuous Corn/Hairy Vetch; Wheat/Rye; Corn/Wheat/Red Clover; Continuous Corn/Red Clover; Continuous Corn/Rye

NPM	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Continuous Silage/Red Clover; Continuous Corn/Red Clover; Continuous Corn/Rye; Corn/Soybean/Red Clover; Corn/Soybean/Rye
NTL	Continuous Corn/Hairy Vetch; Continuous Silage/Red Clover
NTN	Continuous Corn/Hairy Vetch; Continuous Corn/Red Clover
NTR	Continuous Corn/Hairy Vetch; Continuous Silage/Red Clover; Continuous Corn/Rye
NTS	Continuous Corn/Hairy Vetch; Corn/Soybean/Hairy Vetch; Corn/Wheat/Red Clover; Continuous Corn/Red Clover; Continuous Corn/Rye; Corn/Soybean/Red Clover; Corn/Soybean/Rye
NTT	Corn/Soybean/Hairy Vetch; Continuous Corn/Red Clover
PAA	None
PAB	Wheat/Crimson Clover; Corn/Wheat/Crimson Clover
PAC	Corn/Wheat/Crimson Clover; Continuous Cotton/Crimson Clover; Continuous Rice/Subterranean Clover
PAD	None
PAE	None
SPH	Wheat/Rye; Continuous Cotton/Subterranean Clover
SPI	Continuous Sorghum/Subterranean Clover; Sorghum/Cotton/Subterranean Clover; Sorghum/Wheat/Crimson Clover
SPJ	Continuous Sorghum/Crimson Clover; Sorghum/Cotton/Subterranean Clover
SPM	Continuous Soybean/Rye; Continuous Soybean/Crimson Clover
SPP	None
SPT	Sorghum/Cotton/Subterranean Clover
STN	Continuous Soybean/Rye; Continuous Soybean/Crimson Clover; Continuous Corn/Crimson Clover
STP	Continuous Cotton/Crimson Clover; Continuous Soybean/Rye; Continuous Soybean/Crimson Clover; Continuous Corn/Crimson Clover
STT	Corn/Soybean/Crimson Clover; Continuous Corn/Crimson Clover

The rotations were created by adding to existing production enterprises a fall cover crop seeding operation and a spring "kill" operation. In select cases, a field disk operation was also added to the fall or spring operations if none otherwise existed to prepare the field for cover crop planting or to plough under the green manure crop in the spring.

Because the cost of seed is a large fraction of the costs associated with cover crop production enterprises, seeding rates are an important parameter in both biomass yield and production cost estimates for cover crop production. In this analysis, seeding rates were kept constant across crops by planting method, as shown in Table 3.

Table 3: Seeding rates by cover crop species and planting method.

Crop	Planting Method	Seeding Rate (lbs/ac)	Price ($/lb)
Crimson Clover	Broadcast Seeder	25	$1.20
	Drill Planter	15	
	No-Till Drill Planter	15	
	No-Tilll Planter	25	
Hairy Vetch	Broadcast Seeder	27	$1.75
	Drill Planter	17	

	No-Till Drill Planter	17	
	No-Tilll Planter	27	
Red Clover	Broadcast Seeder	12	$1.75
	Drill Planter	12	
	No-Till Drill Planter	12	
	No-Tilll Planter	12	
Rye	Broadcast Seeder	130	$0.33
	Drill Planter	90	
	No-Till Drill Planter	90	
	No-Tilll Planter	130	
Ryegrass	Broadcast Seeder	25	$0.79
	Drill Planter	15	
	No-Till Drill Planter	15	
	No-Tilll Planter	25	
Subterranean Clover	Broadcast Seeder	25	$2.25
Sweet Clover	Broadcast Seeder	17	$2.10
	Drill Planter	12	
	No-Till Drill Planter	12	
	No-Tilll Planter	17	

The price of cover crop seeds varies widely from year to year and from supplier to supplier. The prices shown in Table 3 were arrived at by surveying actual 2009 and 2010 seed prices and selecting what appeared to be a representative figure for each crop.

A number of additional operating costs are associated with cover crop production and accounted for in the production budget generator, including additional labor and machinery ownership and repair costs for planting operations and, where necessary, kill operations.

Use of cover crops may also generate changes in commodity crop yield that translate into increased costs (for reduced yields) or increased revenue (for increased yield) associated with cover crop production. Changes in expected yield for cover crop rotations are derived from the EPIC runs, which generate for both conventional and alternative (i.e. with cover crops) production activities both yield and environmental impact estimates. Estimated yield changes are highly rotation-specific and sensitive to soil type, weather, current practice (such as amount of nitrogen application), and cover crop used.

Cover crops used in this analysis are classified as either legumes (the vetches and clovers) or non-legumes (rye and ryegrass). Legumes fix atmospheric nitrogen and therefore increase the availability of nitrogen in the agricultural systems. For systems whose conventional production is nitrogen-constrained, yield may be observed to increase as a result of the nitrogen infusion associated with the legume, for instance. On the other hand, legumes also require water for growth. While the increased organic matter in soils following cover crop integration can increase soil moisture retaining capacity, systems, such as wheat production systems in the northern plains, that commonly leave land fallow for a time to create a reserve of soil water for the commodity crop may suffer a loss of yield when cover crops replace that fallow period and deplete soil moisture.

Because legume cover crops contribute nitrogen to the production system through fixation, they can also potentially generate surplus nitrogen (or a “nitrogen credit”) in systems that already had sufficient nitrogen prior to introduction of the cover crop. Farmers can take advantage of this nitrogen credit by reducing their application of synthetic nitrogen, while still holding yields constant. For this reason, best management practice recommendations often call for reducing a portion of fertilizer application when legume cover crops are used. The appropriate level of reduction is highly sensitive to the factors listed above—soil type, weather, current practices, etc.— as well as to planting date and legume biomass generated, so generalized recommendations for reduction amounts can vary widely (see Table 4).

Table 4: Green manure nitrogen credits by crop.

Growth at the time of killing		
Crop	< 6” [2]	> 6” [2,3]
lb N/a to credit		
Alfalfa	40	60 – 100
Clover, red	40	50 – 80
Clover, sweet	40	80 – 120
Vetch	40	40 – 90

[1] From UWEX Publication A2809 *Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin*.
[2] Reduce credits by 50 lb N/a on sandy, coarse textured soils
[3] Use the upper end of the range for spring seeded green manures that are plowed under the following spring. Use the lower end of the range for fall seedings. If top growth of vetch is more than 12” before killing the cover crop, credit 110 – 160 lb N/a.

To explore the implications of farmers reducing their nitrogen application in response to incorporation of legumes into their planting rotations, this analysis considers three possible nitrogen application scenarios in conjunction with legume cover crops:

1. No adjustment of nitrogen application in response to legume use.
2. Farmer’s reduce applied nitrogen by an amount equal to 30% of the total N content of the legume biomass produced.
3. Farmer’s reduce applied nitrogen by an amount equal to 50% of the total N content of the legume biomass produced.

To calculate amount of applied nitrogen reduction, each rotation was run through EPIC and a yield estimate derived for cover crop biomass. In cases where biomass yields were way off from projected crop-specific yields described in “Managing Cover Crops Profitably” (SAN, 2007), potential heat units associated with the crop were adjusted to more closely approximate the range of likely yields. Biomass N content, and appropriate nitrogen credits for both the 30% reduction and the 50% reduction scenario, were then calculated for each rotation. The calculated level of N reduction was achieved by reducing nitrogen application in the year following cover crop growth; reductions were imposed proportionally across all sources of nitrogen applied in the following year to achieve the desired level of reduction. See Appendix C for an illustration of the nitrogen reduction credits estimated for each rotation on highly erodible soils. (Different results are achieved on non-highly erodible soils because cover crop biomass yields differ when soil characteristics change.)

Crop Budget Generator Estimates

Because it is critical that the production budget information be consistent across both conventional and alternative production enterprises, the crop budget generator was used to re-generate updated production budget estimates for all of the existing REAP enterprises as well as for the newly designed cover crop rotations. See Table 5 for a comparison across budget generator categories of estimated costs associated with a single crop enterprise with and without cover crop production.

Table 5: Per-acre costs associated with a continuous corn rotation on non-tiled, non-highly erodible soil in REAP's APN region, with and without a hairy vetch cover crop.

System Description	Continuous Corn	Continuous Corn with Hairy Vetch
Region	APN	APN
Tiles	None	None
Soil	Non-highly Erodible	Non-highly Erodible
USMP Identifier	RCCC	RCCC
Seed ($)	50.89285714	80.64285714
Nitrogen ($)	77.49890529	77.49890529
Phosphate ($)	21.77795074	21.77795074
Lime ($)	22.8352	22.8352
Potash ($)	38.57701404	38.57701404
Chemicals ($)	25.35348251	25.35348251
Custom Costs	0	0
Irr. Water ($)	0	0
Energy/Fuel ($)	32.1265	40.0987
Misc. Cost ($)	0	0
Mach. Repairs	16.2251	20.8777
Labor ($)	13.4369	16.6028
Marketing/Storage	0	0
Other Var. Costs	0	0
Operating Capital ($)	4.89907196	5.64593944
Overhead ($)	15.95072975	15.95072975
Insurance/Fees ($)	9.734723783	9.734723783
Ownership Costs ($)	45.1175	56.6445
Land Rent ($)	71	71

Total Fixed Costs	$146.70	$158.98
Total Variable Costs	$298.72	$344.26

EPIC: Estimating Environmental Impacts of Cover Crop Rotations

Alternative crop rotations were run through EPIC to calculate the effect of cover crop integration on yield, as well as to compute changes in environmental indicators per acre for each alternative cropping system, such as nitrogen loss, soil carbon sequestration changes, and other greenhouse gas emissions. Because estimates for the conventional rotations must be consistently estimated with those of the alternative cover crop rotations, all conventional input files also had to be updated to be compatible with the most recent version of EPIC and all impact estimates re-generated for conventional crop rotations as well.

Once EPIC outputs are calculated and imported into REAP, REAP combines the per-acre impact estimates with actual acreage data for each regional rotation to compare national-level environmental performance and production measures (derived from EPIC) with existing national estimates of total crop production, as well as select environmental indicators such as erosion, soil carbon sequestration, etc. REAP then adjusts select EPIC estimates, as needed, to make the simulated scaled up estimates consistent with the national scale estimates. This adjustment process ensures that the variability predicted by EPIC in terms of yield performance and impacts across production practices and soil types (or regions) is maintained, but absolute performance levels are adjusted proportionally to correct for possible over- or under-estimation by EPIC and to ensure that aggregate performance nationwide falls within expected ranges.

Because nitrous oxide emissions are not calculated by the current version of EPIC, N_2O emissions from fertilizer use are derived using the same method as the USEPA Greenhouse Gas Inventory and are calibrated to their estimate.

The adjusted yields and environmental impacts for the production enterprise whose costs are shown in Table 5 are shown in Table 6. This rotation represents a case where, as expected, including the hairy vetch cover crop reduces erosion and nitrogen lost through surface water pathways (sediment and runoff) and reduces soil carbon loss. In this particular case, however, despite the fact that the Hairy Vetch fixes atmospheric nitrogen and introduces additional nitrogen into the system, corn yields drop by a very small amount when grown after the vetch. The failure to increase yields is in part due to the fact that the original system was not highly nitrogen-constrained (as measured by the nitrogen stress measurement). Furthermore, the introduction of the cover crop significantly increases both water and temperature stress in the system, which exerts negative pressure on yields.

Table 6: Yields and environmental impacts associated with a continuous corn rotation on non-tiled, non-highly erodible soil in REAP's APN region, with and without a hairy vetch cover crop.

System Description	Continuous Corn	Continuous Corn with Hairy Vetch
Region	APN	APN
Tiles	None	None
Soil	Non-highly Erodible	Non-highly Erodible

USMP Identifier	RCCC	RCCC
Corn Yield (bushels)[a]	137.95	136.82
Precipitation	52.16	52.16
Irrigation Water	0.00	0.00
Water passing through tiles	0.00	0.00
Surface runoff	11.33	8.18
Subsurface flow	0.96	0.90
Leaching	12.04	8.30
Total Erosion (Tons)	2.45	1.97
Nitrification	0.00	0.00
Denitrification	29.94	30.46
Nitrogen Volatilization	0.00	0.00
Nitrogen Fixation (lbs)	0.00	25.08
N lost through Sediment (lbs)	79.35	67.86
N lost through Runoff (lbs)	27.01	20.59
N lost through Subsurface Flow (lbs)	10.58	16.53
N lost through Leaching (lbs)	31.49	30.28
N lost through Tiles (lbs)	0.00	0.00
P lost through Leaching (lbs)	2.46	1.69
P lost through Sediment (lbs)	5.53	2.73
P lost through Runoff (lbs)	2.84	1.51
Evapotranspiration	27.66	34.64
Nitrogen in Yield (lbs)	71.55	73.21
Phosphorus in Yield (lbs)	8.55	8.43
N Applied (lbs)	135.55	135.55
P Applied (lbs)	20.29	20.29
Measure of Water Stress	26.02	32.50
Measure of Phosphorus Stress	0.00	0.00
Measure of Nitrogen Stress	0.79	0.00
Measure of Temperature Stress	2.80	28.80
Change in Soil Carbon (Tons)	-0.35	-0.10

[a] Yield adjustment also includes an inflation factor that captures expected increases in yield productivity up until the year of the analysis, which in this case is 2015.

Policy Impact Scenarios

The policy impact analyses assume that all non-economic obstacles to cover crop adoption have been removed, so that subsequent adoption of cover crops in response to policy drivers is determined solely by the impact of those drivers on the costs and returns of alternative production systems versus the conventional systems that don't integrate cover crops. In this case, the baseline against which policy scenarios are compared represents a hypothetical snapshot of the current production system with non-economic obstacles to adoption removed but without additional adoption incentives.

The production system depicted in this scenario's baseline projects 9.7 million acres of cover crops divided across the farm production regions as shown in Table 7. The bulk of the acreage deemed to be "cover crop ready" is found in the Appalachian, Northeast, and Southern Plain regions, with the smallest incidence occurring in the Corn Belt. The distribution of that acreage across cover crop species is shown in Table 8. Note that the "winter wheat" crop acreage refers to winter wheat as a green manure crop that is plowed under in the spring, which distinguishes it from winter wheat acreage that is harvested as a conventional commodity crop.

Table 7: Baseline acres of cover crops by Farm Production Region.

Farm Production Region	Acres (millions)
AP	1.66
CB	0.07
DL	0.43
LA	0.81
NP	0.68
NT	2.37
SE	0.54
SP	3.16
Grand Total	9.71

Table 8: Baseline acres of cover crop by species.

Cover Crop Species	Acres (millions)
Hairy Vetch	2.08
Crimson Clover	0.54
Subterranean Clover	0.44
Red Clover	2.95
Rye	0.52
Winter Wheat	2.13
Ryegrass	1.05
Total	9.71

The incidence of cover crops under this scenario, and the achievement of environmental gains associated with cover crop adoption, is highly sensitive to policy incentives that change relative costs and returns between alternative and conventional production systems. This analysis explores the impact on cover crop adoption (and related environmental performance) associated with the following policy incentives:

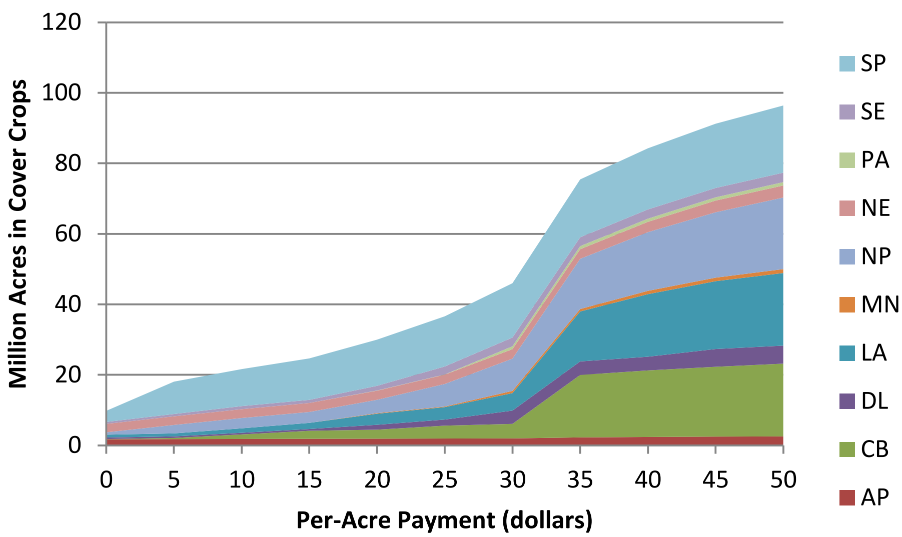
- A flat per acre subsidy for adoption of cover crops into conventional rotations
- A flat per acre subsidy for adoption of cover crops on highly erodible lands only
- A subsidy to offset the cost of cover crop seeds
- A per-unit payment for decreases in GHG emissions
- A per-unit payment for decreases in nitrogen lost to water pathways at the edge of field

Furthermore, because the impacts of nitrogen-fixing cover crop adoption depend on the extent to which nitrogen application is adjusted in response to introduction of a legume into the rotation, calculations were made for the three cases described above: no nitrogen adjustment, nitrogen application reduced by 30% of biomass N, and nitrogen application reduced by 50% of biomass N.

Per-acre Cover Crop Payments

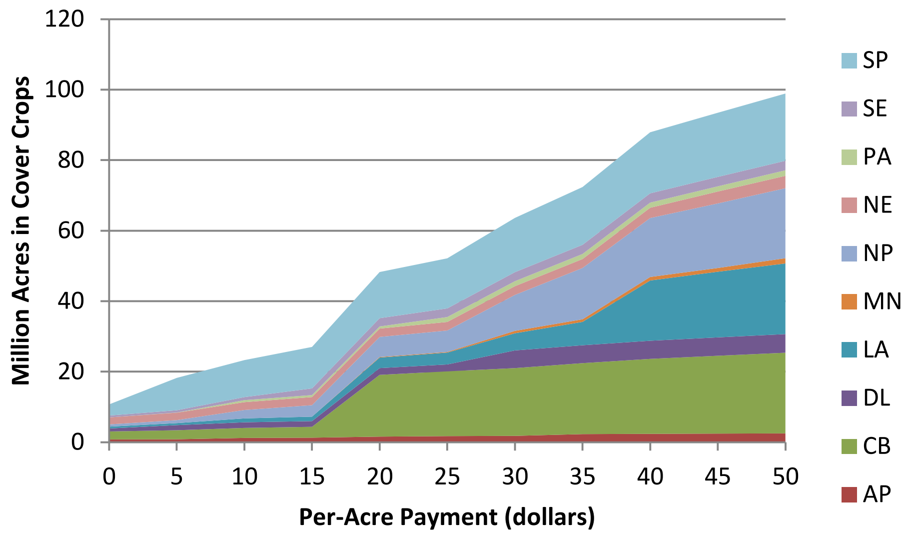
To explore the impact of acreage payments on cover crop adoption, the payment offered was varied from \$5 to \$50 per acre. The resulting adoption of cover crops, broken out by region, is shown in Figure 2. While acreage in the southern plains is quick to adopt cover crops, even at low per-acre payment levels, acreage in the northern plains and lake states rises steadily with higher payment levels, and significant acreage in the corn belt is only brought in when payments exceed \$30 per acre.

Figure 2: Cover crop adoption in response to per-acre payment, broken down by Farm Production Region.



When farmers are assumed to reduce nitrogen application by 30% of biomass N, the profile of adoption changes largely due to the behavior of adoption in the corn belt (Table 3). When nitrogen application is reduced, the cost-effectiveness of nitrogen-fixing cover crops increases if the savings associated with applied nitrogen reduction exceeds any potential costs associated with reduced yields. That is clearly the case for the CornBelt, where the minimum payment required to induce significant adoption of cover crops drops from \$30 per acre to \$15 per acre.

Figure 3: Cover crop adoption in response to per-acre payment, assuming a nitrogen credit of 30% of cover crop biomass N.

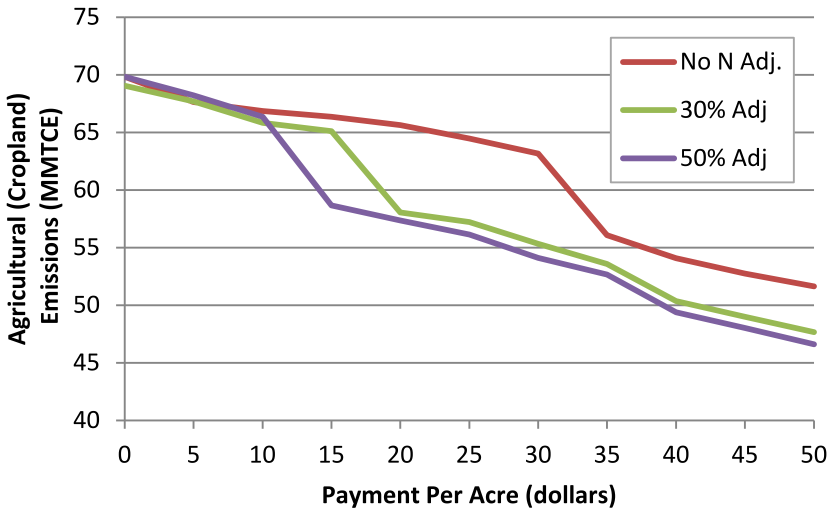


A further reduction in applied nitrogen to 50% of biomass N results in a further shift in cover crop adoption in the Corn Belt. To avoid repetition, in subsequent analyses, only the results associated with the 30% biomass N reduction in fertilizer will be presented.

Environmental Impacts

The environmental impacts associated with agricultural production are impacted by both dimensions of cover crop adoption; the extent and location of adoption, and the degree to which applied nitrogen is reduced in response. One environmental indicator that is particularly sensitive to the adoption of cover crops is the GHG emissions associated with cropland agriculture, which drops significantly as cover crops are adopted, and with the degree of synthetic N displacement, as shown in Figure 4.

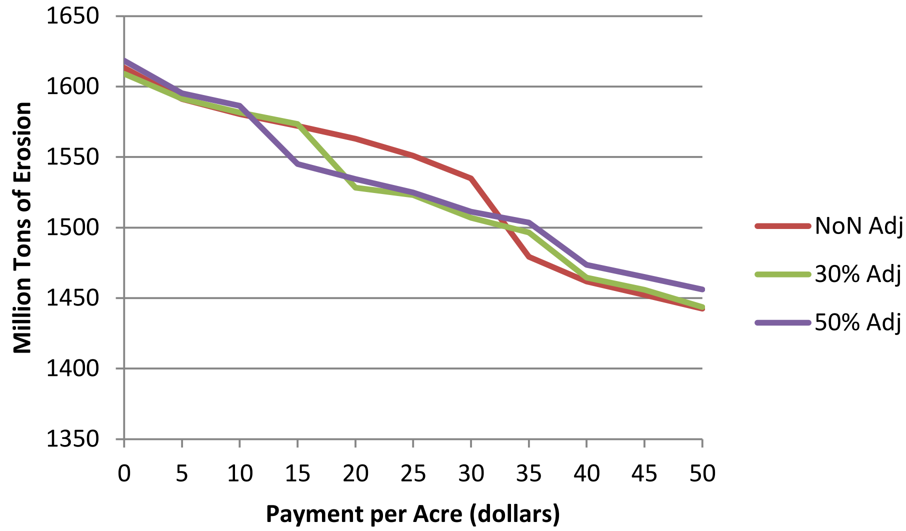
Figure 4: Impacts of per-acre cover crop payment on agricultural GHG emissions under different nitrogen credit assumptions.



The two primary pathways by which GHG emissions are reduced with adoption of cover crops is through increased soil C sequestration and reduced nitrous oxide volatization from the application of synthetic fertilizer. When synthetic N application is not adjusted for nitrogen credits from nitrogen fixing cover crops, the aggregate application of N does not drop much as payments increase and cover crops are adopted; total applied N decreases from 11.77 million tons to 11.60 million tons as you move right along the red line in Figure 4. The drop in GHG emissions along the length of that line is therefore due to increased soil C sequestration, while the drop in GHG emissions moving from line to line is due to reduced N application and N volatization.

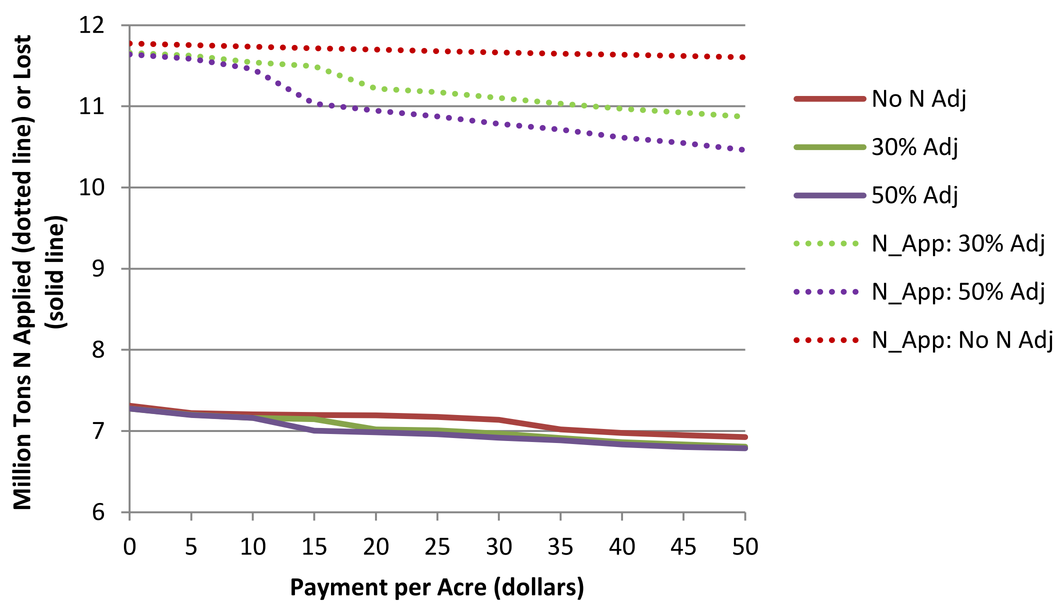
Other indicators of environmental performance are strongly influenced by the adoption of the cover crop but not as sensitive to decisions about nitrogen application. Total erosion (sheet, rill, and wind erosion), for instance, drops significantly as a result of the increased extent of winter cover, year-round biomass, and spring residue, but does not react strongly to changes in nitrogen application (Figure 5). In fact, erosion increases slightly in the case of 50% nitrogen adjustment, which is probably due to slight yield and cover biomass reductions associated with the reduced nitrogen application.

Figure 5: Impacts of per-acre cover crop payment on soil erosion under different nitrogen credit assumptions.



Interestingly, the loss of nitrogen via edge of field water pathways is also relatively insensitive to both cover crop adoption and to decisions made about nitrogen application (Figure 6). It is possible that given the weather pattern used in the EPIC simulation, most N loss problems occur during the spring to fall growing season, which would help explain this dynamic; further research will explore this issue.

Figure 6: Impacts of per-acre cover crop payment nitrogen application and field losses under different nitrogen credit assumptions.



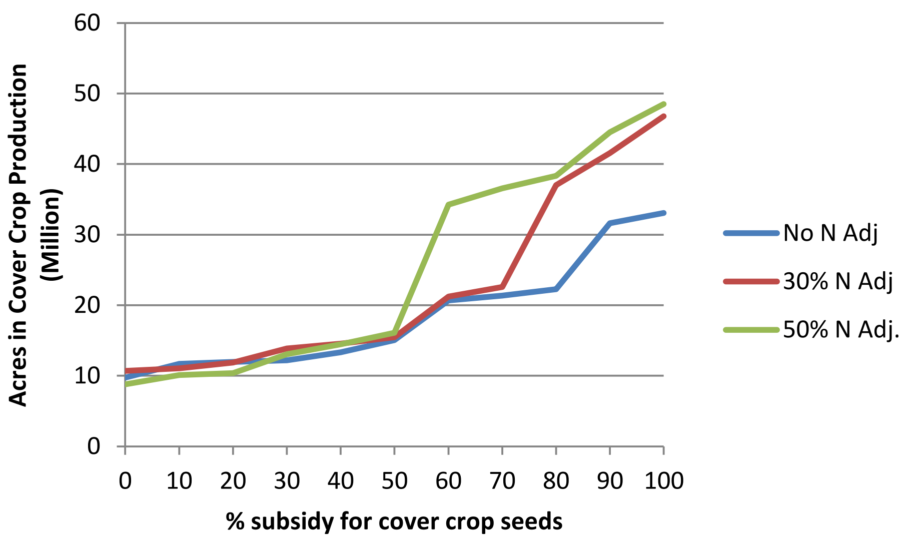
Offering Per Acre Cover Crop Payments only to Highly Erodible Lands

When cover crop payments are offered only to lands on highly erodible soil, the payment is much less effective at drawing acreage into cover crop production. At $50/acre, for instance, only 25.4 million acres are in cover crops (versus 9.7 under the baseline). Most of that acreage occurs in the northern and southern plains, with lesser amounts in the corn belt, lake states, and the north east. That acreage is, as one might expect, disproportionately effective at reducing erosion; erosion is reduced by an average of 3.23 tons per acre brought into cover crop production under the HEL payment restriction, while it is reduced by only 1.97 tons per acre when all lands qualify for the subsidy. The same does not hold true for N lost and GHG emissions, however; in fact, the HEL lands are relatively less effective at mitigating those environmental impacts than the average lands brought in under the open payment policy. That effect may be due to physical properties of the soils or to differences in rotations and practices between the soil types; additional research would be helpful to clarify the pathways through which that dynamic operates.

Subsidizing Cover Crop Seeds

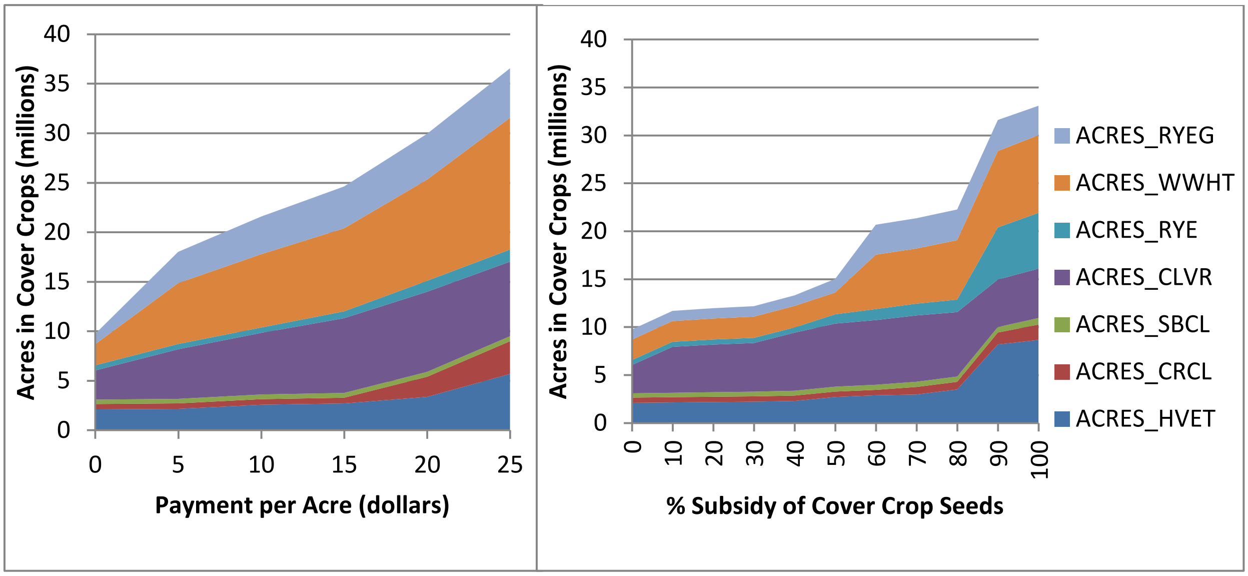
The cost of cover crop seeds is one of the major components of the costs associated with cover crop production. To explore the impact of a subsidization policy, we varied the magnitude of the subsidy from 10% to 100% of the cost of the seed. The acreage results are shown in Figure 7 under the various N adjustment scenarios. A 100% subsidy for cover crop seeds is still well below the $50/acre payment that formed the range for the prior analysis, so the amount of land brought into cover crops is lower under the full range of this policy.

Figure 7: Impact of cover crop seed subsidy on cover crop adoption under different nitrogen credit scenarios.



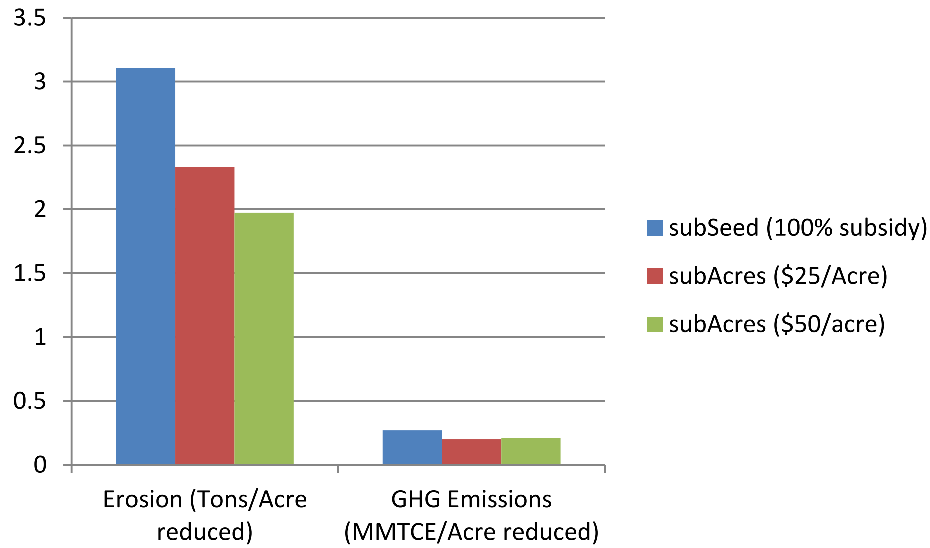
While conceptually similar to the per acre payment described earlier, a seed subsidy behaves differently in that the value of the subsidy varies by cover crop species. The distribution of cover crop species incentivized by the policies therefore differs. Figure 8 illustrates the difference in cover crop composition on roughly the first 35 million acres of adoption between the two scenarios. Note that seed subsidization results in roughly the same proportion of legumes versus non-legumes, but under the legumes, relatively more hairy vetch substitutes for the red and crimson clovers, while under non-legumes, rye substitutes for winter wheat.

Figure 8: Difference in cover crop composition between a per-acre payment and a cover crop seed subsidy.



From the perspective of environmental performance, there are differences in the average mitigation effectiveness of the acreage adopting cover crops over the range of policies illustrated in Figure 8 above. On average, cover crops on the acres brought into production using the seed subsidy appear to be more effective at reducing greenhouse gas emissions, total erosion, and water-borne nitrogen loss than those brought into production using a flat $25/acre payment. The same pattern holds when averages are calculated for the $50/acre payment (Figure 9).

Figure 9: Differences in mitigation effectiveness of cover crop acreage under different policies.



More research will be required to determine exactly how these differences arise. Potential explanations include differences in crop rotations affected, regions affected, or cover crop species composition influenced by the different policies.

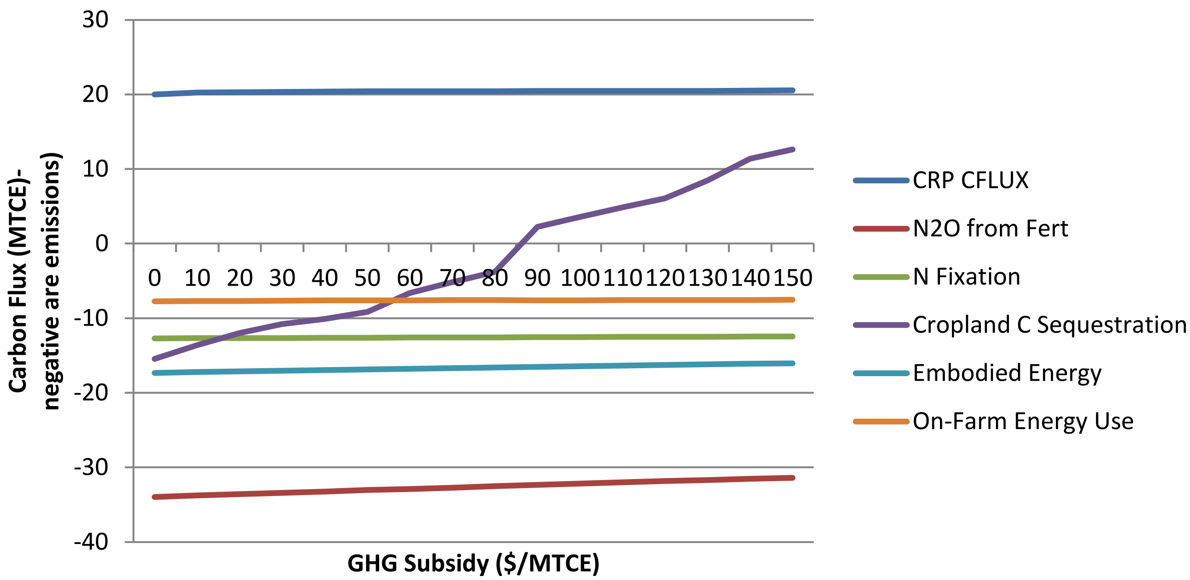
A Per-Unit Subsidy for Decreases in GHG Emissions

The potential for agriculture to supply low-cost GHG mitigation options as part of a comprehensive agricultural offset program has been an important and contentious part of the climate policy debate in the United States. This portion of the analysis explores the responsiveness of agricultural production to a hypothetical carbon market that provides per unit carbon payments that range from $10 to $150 per Metric Ton of Carbon Equivalent.

As illustrated in earlier graphs, cover crops are very effective at decreasing GHG emissions by increasing the carbon sequestered in productive soils. Reductions in N application are also effective at mitigating GHG emissions by reducing the direct and indirect N_2O emissions associated with fertilizer application. The extent to which these different pathways could contribute to an offsets program depends on what practices qualify for offsets under offset program design rules. This analysis assumes that GHG emission reductions that qualify for carbon payments can arise through any production decision that reduces GHGs, including land retirement; other qualifying pathways include changes in tillage, changes in crops or rotations, incorporation of cover crops, or changes in nitrogen use.

The results of this analysis suggest that GHG emission reductions associated with land retirement and adoption of cover crops would be the predominant pathways by which emissions reductions would be achieved given the available potential pathways for reduction (forestry-related pathways, for instance, are not an option in this analysis). As shown in Figure 10, significant emissions reductions are achieved predominantly through changes in cropland C sequestration, and to a lesser extent through reduced N_2O loss and fewer embodied energy emissions implied by reduced fertilizer use.

Figure 10: Agricultural pathways for carbon flux.



Changes in cropland carbon sequestration arise from a combination of land retirement (working land extent drops from 327 million acres to 308 million acres over the modeled range), adoption of cover crops (acreage integrating cover crops increases from ~9 million acres to ~65 million acres), and changes in tillage. Due to confusion in the analysis over how to classify the tillage type of land with winter cover crops, the effects of the latter two impacts (cover crops and tillage) are conflated in this analysis and cannot be disentangled. However, it is possible to eliminate the impacts of land retirement by disqualifying acreage reductions from receipt of subsidies and re-running the analysis. The result of eliminating land retirement as a qualifying pathway is a slight increase in cover crop adoption over the modeled range together with a decline in total GHG reduction emissions achieved (Figure 11).

Because allowing land retirement to receive GHG emissions payments results in an aggregate loss of productive acreage, there are commodity price impacts associated with the GHG payment analysis that don't exist when land retirement is eliminated as a qualifying pathway. The impacts of the policy (with and without land retirement) are shown in Table 9; when land retirement does not qualify to receive GHG payments, the percentage change in commodity prices is lower, and in some cases negative, indicating that prices drop slightly when the payment is available.

Figure 11: Impacts of an emissions reductions payment on agricultural GHG emissions and acres of land in cover crops (CC).

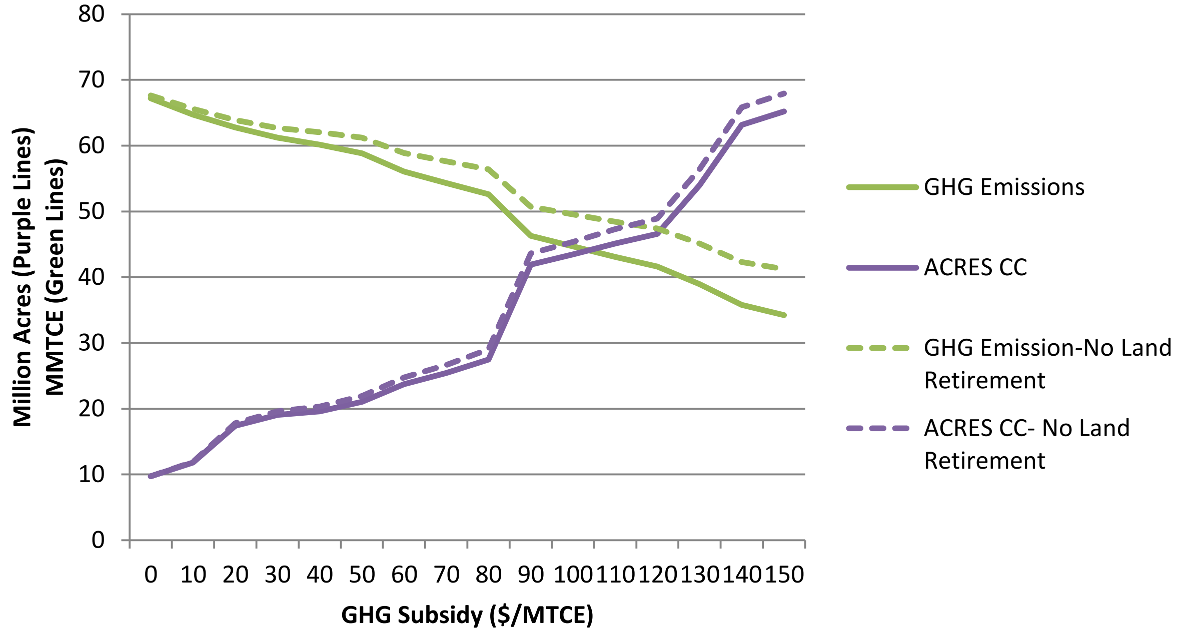


Table 9: Percentage change in commodity prices

	GHG Subsidy ($/MTCE)	50	100	150
barley	No Land Retirement	1.05%	2.13%	3.20%
barley	With Land Retirement	1.46%	1.75%	3.03%
corn	No Land Retirement	0.19%	0.17%	0.07%
corn	With Land Retirement	1.58%	2.70%	3.83%
cotton	No Land Retirement	0.59%	1.11%	1.56%
cotton	With Land Retirement	1.06%	2.02%	3.07%
hay	No Land Retirement	-0.16%	-0.40%	-0.68%
hay	With Land Retirement	0.61%	1.01%	1.84%
oats	No Land Retirement	0.23%	-0.19%	0.48%
oats	With Land Retirement	7.82%	17.94%	21.09%
rice	No Land Retirement	0.04%	0.08%	0.12%
rice	With Land Retirement	0.06%	0.13%	0.20%
silage	No Land Retirement	0.89%	2.26%	4.78%
silage	With Land Retirement	1.13%	4.28%	6.68%
sorghum	No Land Retirement	0.82%	1.68%	2.51%
sorghum	With Land Retirement	1.48%	1.78%	2.61%
soybeans	No Land Retirement	-0.19%	-0.35%	-0.51%
soybeans	With Land Retirement	0.69%	1.30%	2.07%
wheat	No Land Retirement	-0.02%	0.15%	0.27%
wheat	With Land Retirement	0.96%	2.29%	3.89%

In addition to the GHG benefits, the large-scale integration of cover crops has multiple environmental co-benefits, with nitrogen lost to water ways declining by 9% and total erosion declining by 15% over the modeled range (for the case with no land retirement).

For the scenarios where nitrogen application is adjusted for cover crop integration, both the N loss and the GHG emissions decline further as aggregate nitrogen application drops in response to legume introduction and nitrogen credits. Aggregate cover crop acreage, extent of land retirement, and other environmental indicators such as phosphorus loss to waterways and total erosion, are not significantly affected by the introduction of the N application flexibility.

A Per-Unit Subsidy for Decreases in N Loss to Waterways

With the advent of water-quality markets, the potential for nitrogen payments to significantly impact farmer decisions has become a reality in many watersheds throughout the country. This analysis explores the potential impacts on agricultural production of nitrogen reduction payments available nation-wide and ranging from $2.50 to $25.00 per lb.

In accordance with the rules of many pilot water-quality markets, land retirement does not qualify for nitrogen payments in this analysis. All remaining pathways of nitrogen reduction are considered valid, including changes in nitrogen application, crop and rotation choice, and cover crop integration. Nitrogen payments are found to be very effective at incentivizing changes in a number of production practices, including adoption of cover crops and changes in crop and rotation choice, even in scenarios where no nitrogen adjustments or credits are assumed in conjunction with cover crop integration. The results suggest that the drop in nitrogen loss is disproportionately larger than the drop in nitrogen application (Figure 12); because cover crops are so effective at scavenging excess nitrogen to prevent edge of field loss, they become the primary mechanisms through which nitrogen losses are contained (Figure 13). In the scenarios where applied nitrogen adjustments are assumed to reflect nitrogen credits, the policy is even more effective at incentivizing cover crop adoption, with the bulk of the additional adoption coming from legumes (Figure 14).

Figure 12: Impacts of nitrogen reduction payment on nitrogen applied and aggregate field-level nitrogen losses.

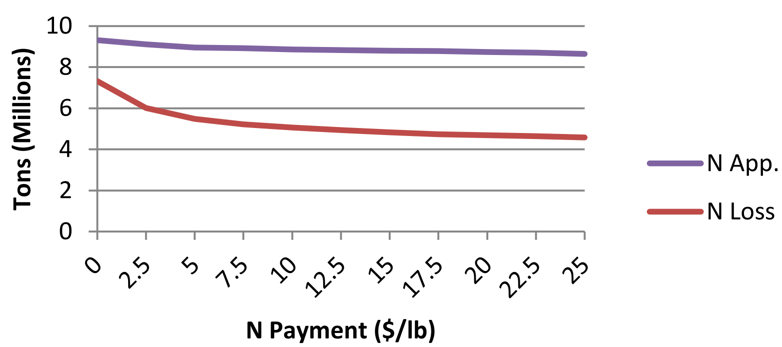


Figure 13: Cover crop adoption with no N credit assumption

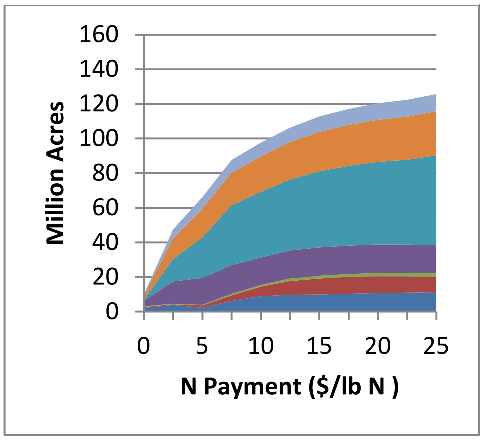
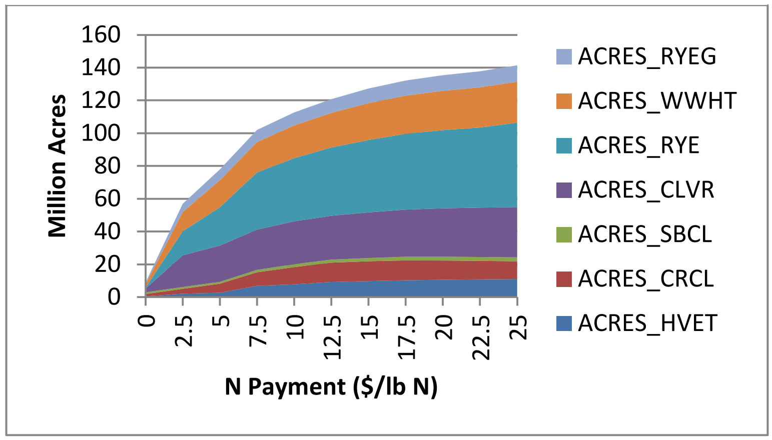
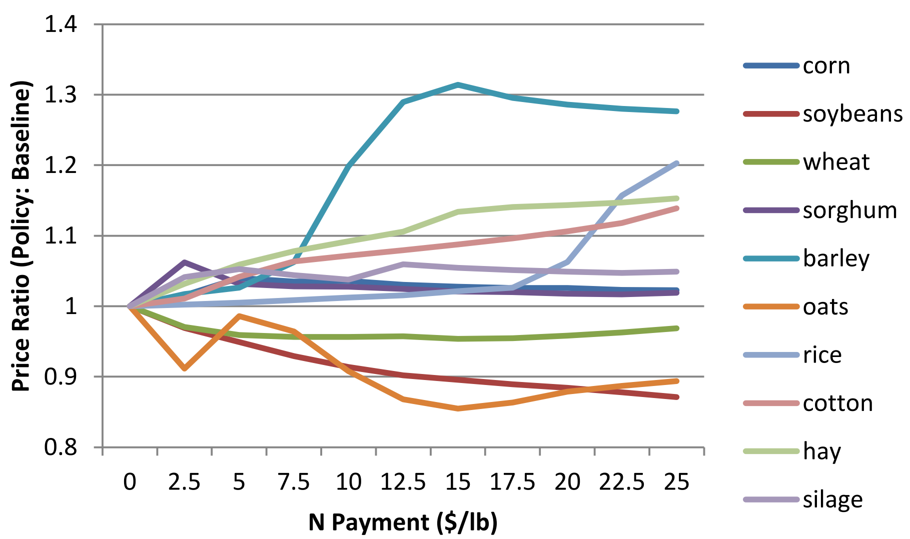


Figure 14: Cover crop adoption assuming a nitrogen credit of 50% biomass N.



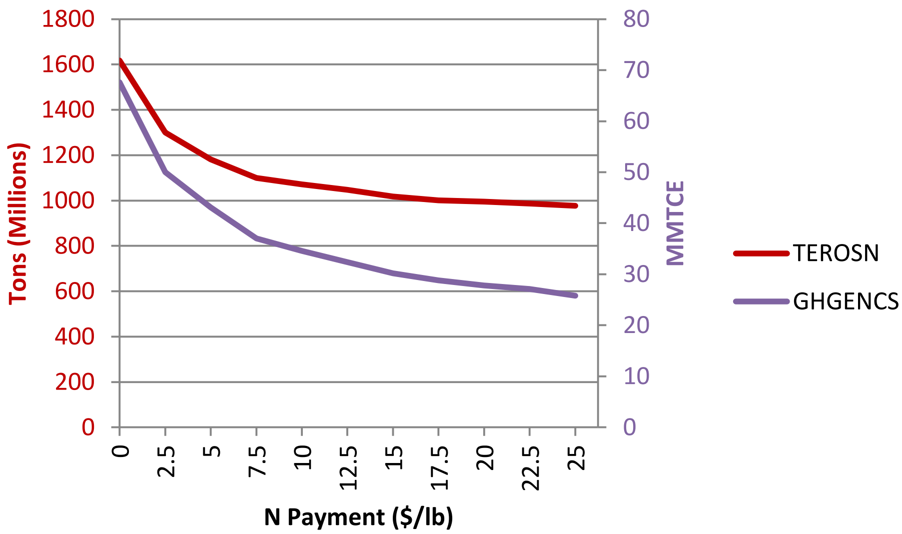
Other projected changes in production patterns include an increase in the production and export of soybeans and soybean oil and a slight shift away from continuous corn toward corn/soybean rotations. Increases in continuous soybean and wheat acreage are accompanied by drops in sorghum, barley, oats, rice, cotton, and hay acreage, with aggregate production acreage remaining roughly constant. The implications for commodity prices are mixed and arise from the combined dynamics of changes in supply arising from farmer production decisions and changes in demand arising from changes in livestock producers' diet decisions and feed demand (**Error! Reference source not found.**). Acreage and production of oats decline, for instance, but so does its price, because demand is lowered as other feed sources, particularly wheat, are substituted into livestock diets.

Figure 15: Impacts on commodity prices of production changes in response to nitrogen emissions payments.



There are substantial environmental benefits associated with the adoption of cover crops, and adoption at the scale illustrated here has significant impacts on all the environmental indicators explored. In addition to the anticipated N loss reductions, which are targeted directly through the payment program, there are substantial GHG emissions reductions (through increased soil C sequestration) and erosion reductions arising from increased winter cover.

Figure 16: Impacts of nitrogen emissions payment on agricultural erosion and GHG emissions.



While the modeled range of N payments is quite broad, and it is not likely that we will see market prices of $25/lb N, it is important to note that quite a few of the impacts occur at the low end of the range and that prices below $10/lb are still very successful at incentivizing cover crop adoption.

Conclusions, Limitations, and Future Research

This analysis suggests that, even under current economic conditions, there is substantial room for cover crop adoption, and the accompanying environmental benefits of reduced erosion, increased soil C sequestration, and reduced nutrient loss, if non-revenue obstacles such as a lack of technical information and exposure can be removed. According to this analysis, roughly 9.5 million acres of land would be expected to have cover crop production if only costs and returns are considered.

The policies explored vary in their ability to draw cover crops into production, but certain generalizations can be seen:

- Both policies where the incentive is linked directly to cover crops (cover crop acreage payments or seed subsidies) and more non-specific policies such as carbon payments impact decisions about cover crop use.
- Non-specific policies may also have other significant production impacts, including in particular increased incentives for land retirement.
- Policies that result in a loss of production acreage have corresponding impacts on commodity prices and availability for export.
- Cover crop adoption is associated with a range of environmental benefits including reduced erosion, reduced nutrient loss to water, and reduced carbon flux through increased soil carbon sequestration.
- The magnitude of environmental impact generally correlates with the scale of adoption of cover crops, but there are differences in the average mitigation effectiveness of the acreage adopting cover crops over the range of policies for different environmental indicators. On average, for instance, cover crops on the acres brought into production using the seed subsidy appear to be more effective at reducing greenhouse gas emissions, total erosion, and water-borne nitrogen loss than those brought into production using a flat $25/acre payment. Such differences may arise from differences in crop rotations affected, regions affected, or cover crop species composition influenced by the different policies. A more in-depth analysis of this dynamic would be a valuable contribution to research in this area.
- The cost-effectiveness and benefits associated with cover crop adoption, and the extent to which adoption responds to policy incentives, depend on assumptions made about nitrogen credits from legume cover crops. This analysis considered fixed assumptions about nitrogen credits and fertilizer displacement (i.e., always no nitrogen adjustment, 30% of cover crop biomass N adjustment, or 50% of cover crop biomass N adjustment). An optimal N credit strategy, however, would allow such decisions to change by rotation, region, etc.; EPIC runs suggest significant variability across rotations and regions in whether and what nitrogen credit should be considered. If rotations are nitrogen constrained prior to the introduction of the legume, a smaller N credit may be appropriate than if nitrogen was already abundant in the system. This analysis did not include an "optimal N credit" scenario, which would have allowed the rotations to change by region

and tillage in how they calculated the appropriate N credit. This extension of the analysis would be a valuable contribution to research in this area.

- Targeting highly erodible lands specifically for cover crop support will likely result in greater erosion control per support dollar, but that may be at the expense of performance along other environmental dimensions. In this analysis, highly erodible lands were found to be less effective at mitigating GHG emissions and N loss to water ways than the average mix of land brought into cover crop production under the open payment policy.
- There are substantial cross-market co-benefits derived from carbon and nitrogen markets that incentivize cover crop adoption. Because cover crops generate simultaneous carbon and nitrogen emissions reductions benefits, payments for a single benefit (carbon or nitrogen individually) produce substantial emissions reductions along the other dimension. This co-generation of benefits has implications for ecosystem services market design questions such as stacking of payments in the presence of multiple markets and defining “additionality” in ecosystem services provision on agricultural working lands.
- The EPIC analysis of the response of production rotations to introduction of a cover crop demonstrated significant commodity crop yield responses across rotations and regions, depending on critical factors such as precipitation limitations (exacerbation of water stress) and length of growing season. In this analysis, we looked at nitrogen application adjustments, but we were not able to represent many of the other ways in which farmers in different regions might adjust their production decisions to accommodate cover crops, including changing harvest and planting dates for commodity crops. Introducing the capacity for such adaptive behaviors would be a valuable extension of this research as well as an interesting segue into questions related to how the patterns of adoption illustrated here might vary under a climate change regime with regional changes in precipitation and growing season temperatures.

Non-revenue barriers to adoption of cover crops are likely a significant obstacle to the mainstream adoption of cover crops that must be explicitly addressed if supplemental policies are to be as effective as possible at generating environmental benefits. Without additional information on the costs of addressing technical, institutional, and informational barriers to adoption, it is not possible to assess the cost-effectiveness of a strategy of investing in reduction of non-revenue barriers versus one of using subsidies and support to incentivize cover crop adoption. A comprehensive study looking at such tradeoffs, and in particular at the environmental benefits associated with investments in lowering informational and institutional barriers to adoption, would be a valuable contribution to the policy debate.

This analysis is, to the our knowledge, the first national-scale analysis of the potential for cover crop adoption in the United States, the response of adoption to various agricultural policies, and the impacts of such adoption along both environmental and macro-economic dimensions. As illustrated above, many research questions and extensions remain that are of immediate policy relevance; this study has also enabled us to create a strong technical foundation for future research on cover crop adoption and impacts using the REAP model. That technical capacity, developed at World Resources Institute under the auspices of this project, has also been shared with the USDA to augment that agency's capacity for future research in this area.

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