policy brief

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Greenhouse Gas Mitigation Opportunities for Agricultural Land Management in the United States

Lydia Olander and Alison Eagle[1]

Agriculture currently contributes approximately 6% of total greenhouse gas (GHG) emissions in the United States.[2] Although increases in efficiency and improvements in management reduce emissions per unit of production,[3] the demand for increased production will likely outpace these improvements, leading to a net rise in emissions, without additional investment. A wide range of on-farm management practices can help to reduce these emissions and generate significant increases in carbon sequestration. Government, industry, and voluntary efforts are under way to incentivize such practices by creating new business opportunities or revenue for farmers and ranchers. The hoped-for outcome is accelerated innovation and adoption of practices that simultaneously mitigate emissions, improve resilience to climate change, and support the nutritional and energy needs of a growing population.

Key Points

- Of 42 management practices reviewed, 28 are likely to sequester carbon or reduce emissions of greenhouse gases; for 8 of these promising activities, there are still some significant data gaps, so uncertainties remain.
- High priorities for research include understanding soil carbon storage at depth, broader assessment of nitrous oxide management strategies, and the stability and life-cycle implications of biochar applications.
- Direct measurement is needed for programs targeting innovation, whereas models may be the most efficient and accurate approach for scaling up well-studied management practices.
- The United States has enough data and sufficiently well-calibrated and -tested models to apply regional or farm-scale approaches to quantifying greenhouse gases for more common and well-researched practices.
- User-friendly and streamlined versions of models will be needed for consistency and verification.
- Models can produce low-cost and transparent farm-scale baseline estimates, as long as farm-level management data can be collected in a low-cost and verifiable manner.
- Development of performance standards is difficult given uneven data on land management.
- Leakage and reversal of stored carbon are issues for only a subset of practices, and many policy approaches are available to address them.

To achieve a balance of increased production and reduced environmental impacts, government programs and corporate supply-chain initiatives seek to motivate the use of increasingly efficient, intensive, and sustainable agricultural practices. New initiatives and programs that target GHG mitigation are considering market mechanisms (e.g., emission offsets) or other performance-based metrics (e.g., life-cycle analysis) for tracking success and making payments or purchases contingent on environmental outcomes. These initiatives and programs require information on the crops, management practices, and new technologies that can enhance GHG mitigation—information such as their viability in different regions, their economic costs or savings, their effect on production, and their net GHG emissions. In addition,

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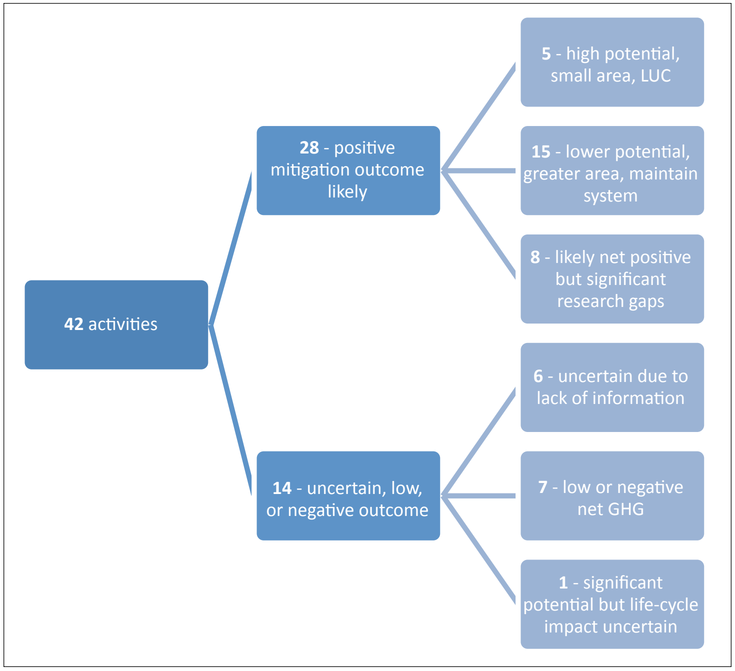
[1] Olander is Director for Ecosystem Services at the Nicholas Institute for Environmental Policy Solutions, Duke University; Eagle is a former Research Scientist at the Nicholas Institute. The project relied on the input from numerous experts, including Justin Baker, Karen Haugen-Koyzra, Brian C. Murray, Lucy R. Henry, Alexandra Kravchenko, Neville Millar, G. Philip Robertson, Keith Paustian, Stephen Del Grosso, William Salas, Cesar Izaurralde, Robert B. Jackson, and Charles Rice.

[2] U.S. Department of Agriculture, *U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990–2008*, Technical Bulletin No. 1930 (Washington, D.C.: U.S. Department of Agriculture, 2011), i.

[3] J.A. Burney, S.J. Davis, and D.B. Lobell, "Greenhouse Gas Mitigation by Agricultural Intensification," *PNAS* 107, no. 26 (2010), 12052–7.

Figure 1. Mitigation potential of agricultural management practices included in T-AGG assessment report (2011).



performance-based approaches require quantification and verification of outcomes.

The Technical Working Group on Agricultural Greenhouse Gases (T-AGG) was formed to help assemble and provide this basic information. The T-AGG assessment covers a wide range of agricultural practices for principal cropping systems in the United States.[4] It provides a roadmap and resource for programs and initiatives that are designing protocols, metrics, or incentives to engage farmers and ranchers in large-scale efforts to enhance GHG mitigation on working agricultural land in the United States.

In assembling information about agricultural GHG mitigation, T-AGG takes into account an evolving range of government and business policy and program options, from cap-and-trade laws to voluntary market and federal payment programs and corporate supply-chain requirements. It provides a side-by-side comparison of net biophysical GHG mitigation potential (soil carbon [C], land emissions of methane [CH_4] and nitrous oxide [N_2O], and upstream or process emissions) for 42 agricultural land management activities synthesized from existing research.[5] It also summarizes a survey that assesses the scientific community's confidence in the mitigation potential of these activities, given often limited data[6] and highlights research coverage and gaps.

This assessment identified 28 agricultural land management activities likely to be beneficial for GHG mitigation (Figure 1). Five have relatively high mitigation potential due to land use changes and are applicable in only some regions (Figure 2). Fifteen tend to have lower mitigation potential, do not shift land use, and are applicable in many U.S. regions (Figure 3). The remaining eight have significant data gaps and need additional research. These activities include increased cropping intensity, agroforestry, histosol management, and rotational grazing for soil C sequestration or conservation, as well as irrigation improvements and improved manure application for N_2O emission reduction. Rotational grazing on pasture lands is particularly interesting. While the C sequestration potential from this practice seems positive, its broader impact on the efficiency of livestock production and the potential for broader mitigation effects is even more promising.

For the fourteen remaining activities, mitigation potential was uncertain, low, or negative. Six of these activities may deserve additional attention as they have been little studied or studies have yielded variable results. Seven of these activities have low or negative net GHG mitigation potential. The final activity, biochar application, may have significant potential, but research on the magnitude of this potential and on life-cycle implications is needed.

A list of all 42 activities and their mitigation potential based on existing studies can be found in Table 1. A mean mitigation potential was determined for those activities with data sufficient. Table 2 presents a literature-based range for those activities with fewer data.

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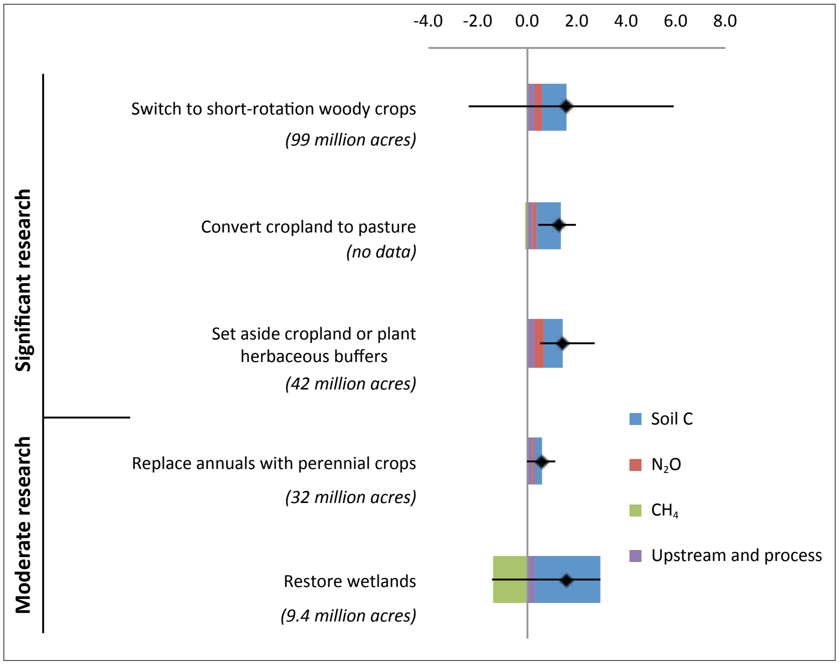
[4] L.P. Olander et al., *Assessing Greenhouse Gas Mitigation Opportunities and Implementation Options for Agricultural Land Management in the United States*, Technical Working Group on Agricultural Greenhouse Gases (T-AGG) report (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, forthcoming).

[5] A.J. Eagle et al., *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature, 2nd Edition*, T-AGG report (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, 2011), http://nicholasinstitute.duke.edu/ecosystem/land/TAGGDLitRev.

[6] A.J. Eagle et al., *T-AGG Survey of Experts: Scientific Certainty Associated with GHG Mitigation Potential of Agricultural Land Management Practices*, T-AGG report (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, April 2011), http://nicholasinstitute.duke.edu/ecosystem/t-agg/survey-of-experts.

Figure 2. Mitigation potential of agricultural practices that (1) result in land use changes or significant crop mixture changes; (2) are backed by significant research, about which scientific certainty is moderate to high; and (3) are likely to result in a net GHG reduction.



Note: The bars show an average expected change in soil C, N_2O, and CH_4 emissions and in process and upstream emissions. The range line is based on the range in GHG change (80% of observations within the range) for the gas targeted by the management shift. The numbers in parentheses are an estimate of maximum area based on the extent of appropriate croplands and their existing management.

The adoption of these management practices primarily depends on their economic potential, given the opportunity cost of various cropping and management options, the costs and benefits of adoption, and other socioeconomic variables. With a limited land base and a large suite of management options, producers must choose what works best for them. The T-AGG assessment report[7] summarizes studies in the published literature that document the economic and competitive potential of select management practices at various C prices. Only a limited suite of activities has been covered in these studies, which focus on fallow lands and tillage reduction, conversion of cropland to permanent grass or other forage, and afforestation. Higher payments for carbon tend to generate more GHG mitigation and cause shifts in the activities. Reduced-tillage practices are incentivized at lower prices; conversion of cropland to forest or perennial grass becomes more prevalent only when prices rise (even though biophysical potential is greater per unit area, compared with tillage changes). Although model predictions can provide useful guidance, they cannot fully account for transaction costs, farm-level adoption barriers, and environmental co-benefits, all of which can affect the willingness of producers to shift various management practices.

Measuring GHG outcomes from agricultural management projects in a manner that fosters confidence but keeps costs low has been a significant challenge. Field-based sampling is appealing in its tangibility and is likely the best approach for programs focused on innovation. But variability (within soils and across fields, seasons, and rainfall events) and technical limitations can make achieving sufficient levels of certainty relatively expensive. Thus, scientific experts suggest that modeling is a better approach for large-scale implementation of known and tested management activities. Modeling options range from simple, national default factors and regional or ecozone-specific factors to the detailed, farm-level application of process models. The United States has enough data and sufficiently well-calibrated and -tested process-based models to apply regional or farm-scale approaches for most activities supported by moderate levels of research. Regional-scale approaches are less complex to implement but are less flexible than farm-based approaches.

Process-based biogeochemical models can simulate GHG dynamics under a range of changing environmental (soil physical properties, climate, topography) and management (cropping, livestock, manure, grazing practices) variables, while capturing temporal and spatial variability.[8] These models are based on and calibrated with field research and data, but they are sometimes limited in their accuracy due to research gaps or insufficient calibration with existing research. But they can be refined as research evolves. Due to the complexity of the models, user-friendly and application-specific versions, such as COMET-Farm,[9] will be needed for consistent and verifiable use in protocols and programs.

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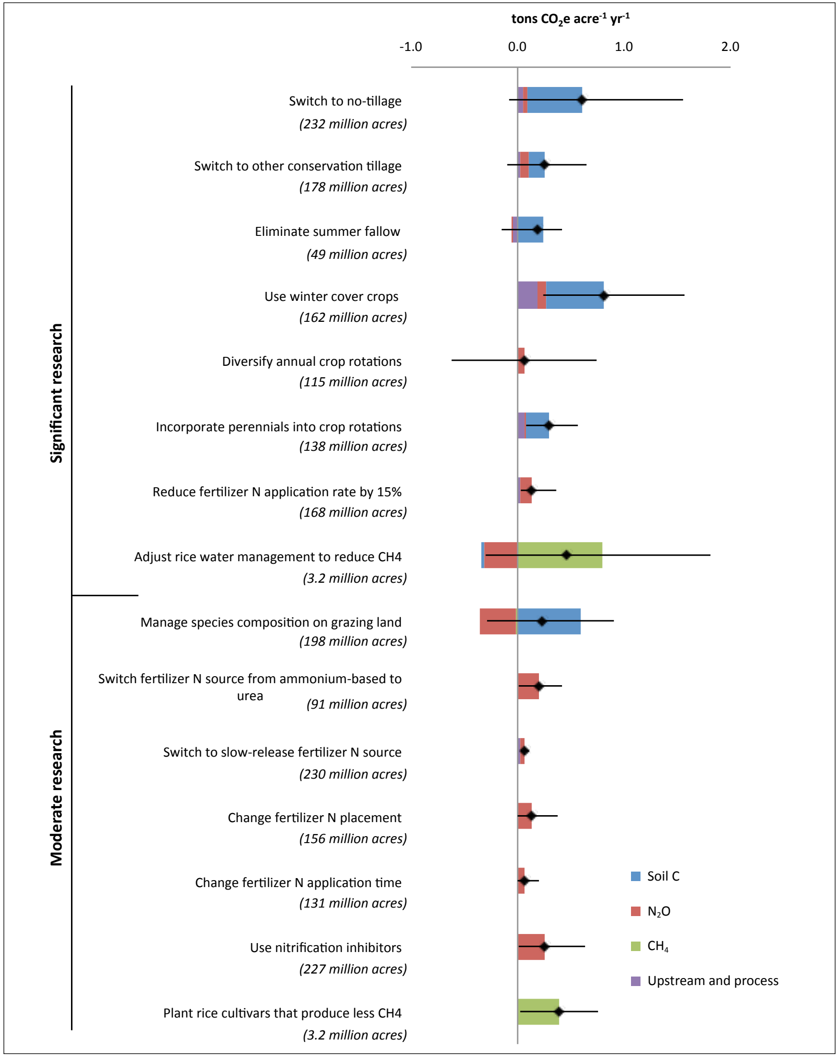
[7] See note 4.

[8] L.P. Olander and K. Haugen-Kozyra et al., *Using Biogeochemical Process Models to Quantify Greenhouse Gas Mitigation from Agricultural Management Projects*, T-AGG report (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University, March 2011), http://nicholasinstitute.duke.edu/ecosystem/t-agg/using-biogeochemical-process.

[9] See text box about COMET-Farm in L.P. Olander et al. 2011 (note 4).

GHG accounting frameworks for many protocols and programs will require clear guidance for calculating baselines, determining additionality, addressing reversals in C storage, monitoring and verifying outcomes, and accounting for leakage. (These terms and their relevance for accounting are described in detail in the T-AGG assessment report.[10]) Standardized approaches for baseline and additionality, which use data on national, regional, or sectoral trends, are commonly used by programs in the United States because they reduce transaction costs and increase transparency. These approaches require aggregated data on agricultural management practices, which may not always be available at the level of detail needed. If farm- or project-scale approaches for baseline determination are used instead, their application must be consistent and their results verifiable. Meeting these requirements may be possible with the development of standardized user interfaces for process-based models. As long as farm-level management data can be gathered in a low-cost and verifiable manner, process-based models can produce low-cost and transparent farm-scale baseline estimates.

Figure 3. Mitigation potential of agricultural management practices that (1) do not result in land use changes or significant crop mixture changes; (2) are backed by significant research, about which scientific certainty is moderate to high; and (3) are likely to result in a net GHG reduction.



Note: The bars show an average expected change in soil C, N_2O, and CH_4 emissions and in process and upstream emissions. The range line is based on the range in GHG change (80% of observations within the range) for the gas targeted by the management shift. The numbers in parentheses are an estimate of maximum area based on the extent of appropriate croplands and their existing management.

Bad or negative leakage will be an issue where management practices—such as reducing nitrogen fertilizer rates, reducing animal stocking rates on grazing lands, switching from annual to perennial crops, or setting aside cropland—could reduce productivity. Given the loss of profits that may come with reduced productivity, these activities may be less viable choices for producers unless greater compensation is available. Many methods, such as leakage discounts, can be used to address leakage impacts. Output- and yield-based performance accounting methods (e.g., tonnes of GHGs per tonne of corn) incorporate both positive and negative leakage and reward improvements in production efficiency.[11]

For many of the reviewed agricultural practices, reversals are not an issue (e.g., for avoided N_2O and CH_4 emissions) or are only a short-term concern (e.g., elimination of cover crops for a single year) for which management can compensate. Cessation of management practices that sequester soil C tend to be intentional—as when conventional tillage

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[10] See note 4.

[11] B.C. Murray and J.S. Baker, "An Output-Based Intensity Approach for Crediting Greenhouse Gas Mitigation in Agriculture: Explanation and Policy Implications," *Greenhouse Gas Measurement and Management* 1, no. 1 (February 2011), 27–36.

is reintroduced on land not tilled for many years—and the loss of stored carbon tends to occur slowly. Only those few practices that involve aboveground biomass, such as windbreaks, can result in significant immediate unintentional releases, such as those typical of forestry projects. How programs will handle the uncertain effects of climate change on the risks of reversals of stored carbon remains unclear. Despite this and other uncertainties, the work of T-AGG suggests the knowledge, data, and methods are sufficient to move forward on a number of options for mitigating GHG emissions on agricultural lands in the United States.

Table 1. U.S. agricultural land management activities with positive GHG mitigation potential and significant to moderate research coverage.

Activity	Soil carbon	N_2O emissions	CH_4 emissions	Process & upstream emissions	Nat'l total	Max area	Comments
	mean (range); t CO_2e acre^{-1} yr^{-1}					Million acres	
Significant research							
Switch to no-till	0.51[*] (-0.17–1.46)	0.04	0.00	0.05	1.49 (-0.20–3.85)	232	N_2O emissions, which are well studied, depend on soil and climate.
Switch to other conservation tillage	0.15 (-0.21–0.55)	0.07	0.00	0.03	0.26 (-0.10–0.65)	178	Soil C change varies by region.
Eliminate summer fallow[†]	0.24[*] (-0.09–0.49)	-0.01	0.00	-0.05	0.18 (-0.15–0.42)	49	Process and upstream emissions depend on N fertilizer rates for crop replacing fallow.
Use winter cover crops	0.54 (-0.03–1.30)	0.08	no data	0.19	0.81 (0.24–1.57)	162	This activity can reduce need for fertilizer N, but it may require timing changes for the main crop.
Diversify annual crop rotations	0.00[*] (-0.68–0.67)	0.07	0.00	0.00	0.07 (-0.62–0.74)	115	Net primary productivity is the key factor.
Incorporate perennials into crop rotations	0.21 (-0.004–0.49)	0.01	0.00	0.07	0.29 (0.08–0.56)	138	
Switch to short-rotation woody crops[‡]	1.02 (-2.97–5.37)	0.31	no data	0.26	1.59 (-2.40–5.94)	99	Upstream emissions do not include end use. Negative soil C results are limited to studies of less than six years.
Convert cropland to pasture[‡]	0.97 (0.16–1.69)	0.19	-0.10	0.18	1.24 (.43–1.96)	no data	The total area is uncertain.
Set aside cropland or plant herbaceous buffers[‡]	0.80 (-0.15–2.05)	0.34	0.00	0.30	1.44 (0.49–2.70)	42	This activity excludes histosols. Differences in types of land for restoration result in a wide range of mitigation potential.
Reduce fertilizer N application rate by 15%[‡]	no data	0.11 (0.01–0.33)	no data	0.02	0.13 (0.03–0.36)	168	
Adjust rice water management to reduce CH_4	-0.02	-0.32	0.80 (0.03–2.15)	no data	0.46 (-0.30–1.81)	3.2	U.S. studies are augmented with international data.
Moderate research							
Replace annuals with perennial crops[‡]	0.27 (-0.35–0.81)	0.10	0.00	0.21	0.58 (-0.04–1.12)	32	
Restore wetlands[‡]	2.64 (-0.39–4.00)	0.00	-1.35	0.30	1.59 (-1.43–2.96)	9.4	
Manage species composition on grazing land[†]	0.59 (0.07–1.26)	-0.35	-0.01	no data	0.23 (-0.29–0.90)	198	Emissions of N_2O and CH_4 are based on one study.
Switch fertilizer N source from ammonium-based to urea	no data	0.20 (0.01–0.42)	no data	no data	0.20 (0.01–0.42)	91	
Switch to slow-release fertilizer N source	no data	0.04 (0.02–0.08)	no data	0.02	0.07 (0.04–0.11)	230	Assuming less fertilizer N is used, upstream emissions will be reduced.
Change fertilizer N placement	no data	0.13 (0.00–0.37)	no data	no data	0.13 (0.00–0.37)	156	
Change fertilizer N application timing	no data	0.07 (0.00–0.20)	no data	no data	0.07 (0.00–0.20)	131	
Use nitrification inhibitors	no data	0.26 (0.01–0.63)	no data	no data	0.26 (0.01–0.63)	227	
Plant rice cultivars that produce less CH_4	no data	0.00	0.39 (0.02–0.76)	0.00	0.39 (0.02–0.76)	3.2	U.S. studies are augmented with international data.

Note: The mean for the target gas reflects the average mitigation estimate from field comparisons. The mean for other GHG classes relies on field comparisons as well as expert and model estimates. The range for the target gas indicates the 10th and 90th percentiles of the data (80% of observations within the range). This range is used for the national total (net GHG balance).

[*] These means are regionally weighted. All others are the mean of available observations, given that regionally representative data were insufficient.

[†] These activities may increase agricultural productivity in the project/program area and thus result in positive leakage.

[‡] These activities may decrease productivity in the project/program area and thus result in negative leakage (production shifts elsewhere).

Table 2. GHG mitigation potential for U.S. agricultural land management activities with significant research gaps, life-cycle GHG concerns, and low or negative GHG mitigation implications.

Activity	Target	GHG benefits mean (range) t CO_2e acre^{-1} yr^{-1}	Max area Million acres	Comments
Likely positive, but significant data gaps				
Increase cropping intensity[*]	soil C	no data	unknown	Using winter cover crops and eliminating summer fallow are treated separately as two unique examples of increasing intensity. Data on other options are not available.
Establish agroforestry on cropland (windbreaks, buffers, etc.)[†]	soil C	0.34–2.78	52	Total potential is for area in trees alone, and does not include aboveground C storage.
Improve irrigation management (e.g., drip)	N_2O	0.06–0.38	50	Irrigation improvements may also significantly reduce process and upstream emissions if total irrigation water is reduced.
Improve manure management to reduce N_2O	N_2O	0.15–0.49	30	This activity includes applying manure to dry areas rather than wet ones, using solid instead of liquid manure, and reducing application rates.
Manage farmed histosols	soil C	0.00–6.08	1.9	Total area farmed is highly variable in the literature.
Set aside histosol cropland[†]	soil C	0.89–29.68	1.9	Total area farmed is highly variable in the literature.
Introduce rotational grazing on pasture[*]	soil C	-0.02–1.17	103	With increased forage production per unit area, this activity can have positive leakage effects. However, it may also increase enteric emissions because more cattle can graze on a given area.
Establish agroforestry on grazing land	soil C	0.19–1.47	173	
Significant potential but life-cycle effects uncertain				
Apply biochar to cropland	soil C	0.25–7.92	306	Biochar application raises concerns about effects on the source location and biochar production raises concerns about GHG balance. Recent research suggests the application has the potential to reduce N_2O emissions.
Uncertainty due to lack of data or high variability				
Drain agricultural land in humid areas	N_2O	no data	unknown	
Improve grazing management on rangeland	soil C	uncertain (see text)	561	Expert assessment indicates positive potential for soil C increase, especially on overgrazed land. Research comparisons demonstrate that soil C loss is common with reduced grazing pressure (likely on well-managed rangeland).
Improve grazing management on pasture	soil C	-1.20–1.93	119	
Introduce rotational grazing on rangeland	soil C	-2.13–0.77	unknown	
Improve N use efficiency of fertilizer and manure on grazing land	N_2O	no data	unknown	
Introduce fire management on grazing land	soil C	no data	unknown	
Life-cycle GHG effects/concerns				
Apply organic material (e.g., manure)	soil C	0.07–2.06	21	This activity raises concerns about effects on the source location. Improved manure nutrient distribution might reduce N fertilizer needs (thus lowering upstream emissions).
Convert dry land to irrigated land[*]	soil C	-0.22–1.14	n/a[‡]	GHG costs of irrigation equipment and pumping may negate soil C gains. N_2O emissions are also higher with irrigated land.
Fertilize grazing land[*]	soil C	0.15–2.37	n/a	GHG emissions from fertilizer production may negate soil C gains.
Irrigate grazing land[*]	soil C	0.00–0.74	n/a	GHG costs of irrigation equipment and pumping may negate soil C gains. N_2O emissions are also higher with irrigated land.
Reduce rice area[†]	CH_4	0.94–4.15	3.2	Impacts depend on subsequent land use and conditions for displaced rice production.
Low or negative GHG mitigation for target GHG				
Reduce chemical use (other than N)	upstream/ process emissions	0.01–0.03	302	
Set aside grazing land[†]	soil C	-1.12–0.40[§]	unknown	Soil C response data are highly variable.

Note: The range indicates the minimum and maximum values for the target gas from field comparisons, expert estimates, and model estimates, as available.

[*] These activities may increase agricultural productivity in the project/program area and thus result in positive leakage.

[†] These activities may decrease productivity in the project/program area and thus result in negative leakage (production shifts elsewhere).

[‡] The total area is not estimated for activities for which the net GHG effect is negative.

[§] The 80% range of 28 field comparisons for "setting aside grazing land" is presented. The mean is -0.21 t CO_2e acre^{-1} yr^{-1}.

The **Nicholas Institute for Environmental Policy Solutions** at Duke University is a nonpartisan institute founded in 2005 to help decision makers in government, the private sector, and the nonprofit community address critical environmental challenges. The Institute responds to the demand for high-quality and timely data and acts as an "honest broker" in policy debates by convening and fostering open, ongoing dialogue between stakeholders on all sides of the issues and providing policy-relevant analysis based on academic research. The Institute's leadership and staff leverage the broad expertise of Duke University as well as public and private partners worldwide. Since its inception, the Institute has earned a distinguished reputation for its innovative approach to developing multilateral, nonpartisan, and economically viable solutions to pressing environmental challenges.
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