TECHNICAL WORKING GROUP ON AGRICULTURAL GREENHOUSE GASES
(T-AGG) SUPPLEMENTAL REPORT

T-AGG Survey of Experts
Scientific Certainty Associated with GHG Mitigation Potential of Agricultural Land Management Practices

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DUKE UNIVERSITY

April 2011

Nicholas Institute for Environmental Policy Solutions
Report
NI R 11-05
April 2011

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Acknowledgments
We would like to thank all the scientists who volunteered their time to participate in this survey (see list on the following page), and those who also commented outside of that commitment. We are also grateful for the guidance provided by Lydia Olander and Karen Haugen-Kozyra in the design and implementation of this project. Comments and suggestions on an earlier version of this manuscript by Drs. Robert Jackson, Henry Janzen, and Mark Liebig are gratefully appreciated. Support from the David and Lucile Packard Foundation for the Technical Working Group on Agricultural Greenhouse Gases was also essential to the success of this project.

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Summary

During the climate change policy debate in the United States, discussion about agriculture's role in greenhouse gas (GHG) mitigation was fairly limited and focused mainly on the potential contributions of tillage changes and afforestation. Although a rough list of other activities was suggested by various stakeholders, there was very little sense of the mitigation potential of these other agricultural land management measures. The Technical Working Group on Agricultural Greenhouse Gases (T-AGG) was formed to help assess a wider range of options. One of the first outputs was a synthesis of scientific literature on the biophysical greenhouse gas (GHG) mitigation potential of 43 agricultural land management activities that could be applied in cropping and grazing systems in the United States.

Ideally, a meta-analysis of the research would be used for a robust assessment of mitigation potential and the variability that results from differences in soil, climate, or cropping conditions. However, for many of the activities considered, studies are few and their value varies, as does their coverage of GHG response across regions, soil types, or cropping systems. These limitations hinder formal meta-analysis. To assess the scientific community's confidence in the existing research and to highlight key considerations for a broader range of activities, we conducted a survey of scientific experts, providing qualitative information that could help programs and policy makers make decisions regarding these activities in the near term.

The survey was designed to assess confidence in the mitigation potentials assessed by the literature as well as potential critical uncertainties, regional issues, or other caveats. A key issue for each activity is whether scientists feel that it will most often result in positive GHG mitigation. For this assessment of scientific certainty, the original set of 43 activities was reduced to 28. Activities with no data or with negative GHG impacts were dropped. The remaining activities have positive biophysical GHG mitigation potential (according to the literature) over multiple regions in the United States, high mitigation potential per unit area in limited regions, or both.

The survey took the form of five webinar sessions, in each of which an average of 10 scientists participated. Survey sessions were organized according to topic area: soil carbon (C), nitrous oxide (N_2O) emission reductions, methane (CH_4) or multiple GHG emission reductions, and grazing land management. Qualifiers and caveats for each activity were determined during discussion of each activity, before anonymous votes on scientific confidence and level of supporting evidence.

The voting options for both confidence and evidence were explicitly defined. For example, *medium* and *high* confidence ratings were equated with positive directional certainty, i.e., confidence that the proposed activity offers positive GHG mitigation, even though the magnitude of mitigation might not be well defined. A vote of *high* confidence was given if the expert was "confident that the value is within the range given (i.e., ± 20% of the estimate)." A *low* confidence rating was equated with a lack of directional certainty, i.e., the expert considered the given rate to be an educated guess. Voting on level of supporting evidence was similarly defined; for example, the *medium* option indicated that sufficient data were available to support the conclusion, even if some regions needed further work.

Thirteen of the 28 activities assessed were associated with positive directional certainty. Experts determined that a significant amount of research evidence supports the assertion of positive GHG mitigation potential for many of these 13 activities: switching to no-till, including perennials in crop rotation, switching from annuals to perennials, setting cropland aside or turning it to pasture, managing water in rice production and developing new rice varieties, and improving grazing management on rangeland. These experts determined that little research evidence supports the assertion of positive GHG mitigation potential for other activities: growing short rotation woody crops, managing or setting aside farmed histosols, improving grazing management on pasture, and managing species composition on grazing land. But they understood the underlying biophysical processes sufficiently to assert that these activities would reduce GHG emissions or store carbon.

Experts placed low confidence in the GHG mitigation potential of conservation tillage and organic material application, even though these activities have been significantly discussed and examined in the literature. They determined that the definition of conservation tillage varies widely, leading to confusion. For example, many literature reviews have combined data on no-till with that from other types of conservation tillage to conclude that conservation tillage sequesters carbon. The scientists agreed that too many unresolved life-cycle GHG issues attend organic material application. Because this activity may merely shift organic matter from one site to another, experts had low confidence in its net GHG mitigation.

Scientists often appear conservative relative to other groups when estimating certainty.[1] The survey results may therefore indicate a level of confidence lower than that anticipated by those developing GHG-mitigating protocols, programs, and projects. However, many of the indications of low confidence coincided with a paucity of data, accrual of which could improve understanding and possibly increase certainty. For example, rotational grazing on pasture is expected to accrue soil carbon as a result of productivity gains, but a serious lack of data on the efficacy of this strategy in U.S. pasture systems resulted in low confidence on the part of the survey participants. Similarly, high variability in N_2O flux and measurement challenges led scientists to conclude that more data were needed to ensure that N management techniques would consistently reduce N_2O emissions, especially in lesser-studied regions. Thus, a valuable output of this survey was to identify areas in which understanding is weakest and in which more research is most justified.

[1] That is, they require sufficient data to come to a conclusion.

Introduction

Agricultural land management has the potential to contribute to greenhouse gas (GHG) mitigation by increasing soil carbon (C) sequestration or reducing GHG emissions – most notably emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Certain adaptations in land management (hereafter called "activities") have varying biophysical (i.e., technical) potential for GHG mitigation, and decision-makers, both private and public, need reliable information to help prioritize activities in incentive projects or programs. The Technical Working Group on Agricultural Greenhouse Gases (T-AGG) was formed to help assess options for agricultural GHG mitigation. One of the first outputs was a synthesis of scientific literature on the biophysical GHG mitigation potential of 43 agricultural land management activities that could be applied in cropping and grazing systems in the United States. This information is available in a separate report, *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature* (hereafter the Synthesis Report). The Synthesis Report, used as the foundation for this survey, makes direct side-by-side comparisons of GHG flux impacts for different activities, and the results indicate a wide range of mitigation potential.

Data from field trials can form the basis of comparison, but apparent experimental inconsistencies, insufficient data, or both can reduce confidence in expected environmental performance (i.e., GHG impacts). Ideally, a meta-analysis of the research would be used for a robust assessment of mitigation potential and the variability that results from differences in soil, climate, or cropping conditions. However, for many of the activities considered, studies are few, and their value varies (e.g., it is difficult to compare laboratory versus field experiments, there are experimental design limitations, etc.), as does their coverage of GHG response across regions or soil types. These limitations hinder formal meta-analysis. On the other hand, confidence in the synthesized estimates cannot be based solely on the volume of data available, because an activity with few data points may be associated with rather well-understood biogeochemical cycling processes, low variability by region or soil type, or both. In addition, a large amount of data might not necessarily translate to clear understanding of GHG impacts.

Therefore, we use a survey of experts to assess the scientific certainty of biophysical mitigation potentials reported in current scientific literature. The survey results allow us to (1) identify high-priority agricultural land management activities for the development of incentive-based GHG mitigation policies and programs in the United States, and (2) highlight current data gaps and suggest high-priority future research efforts. Although the survey uses estimates of mitigation potential that are national averages, it does NOT provide default GHG impact (i.e., emission reduction) factors for direct application. Instead, the results set the stage for further development of protocols and programs that can then implement quantification methods appropriate by region, crop type, and other variable factors.

To move forward with incentive-based programs and policies, program managers and developers must know that a given activity results in net mitigation, and they must be able to quantify uncertainty and variability in the GHG outcome in order to apply conservative principles for accounting and crediting. This survey focused primarily on the first criterion, using expert opinion to gauge confidence in mitigation potential and to determine whether an activity had positive directional certainty (i.e., net positive mitigation in the opinion of the experts). By querying the level of evidence supporting the estimates of mitigation potential, the survey may also provide some insight into uncertainty. For example, an activity with positive directional certainty and a high level of evidence would warrant inclusion in an incentive-based program with conservative accounting. On the other hand, an activity with positive directional certainty and a low level of evidence may require additional research before such inclusion.

This report describes methods for the survey, which took place in the fall of 2010, and in which experts were asked to indicate the degree of certainty associated with estimates of biophysical potential drawn from the literature, as well as to give their opinion of the level of evidence supporting these estimates. The report then presents the survey results, starting with a description of qualifiers and caveats that apply to the chosen levels of confidence and evidence. It concludes with an assessment of the certainty associated with GHG mitigation activities and suggests some key areas for future research. The top research priorities are likely in those areas that have good potential to increase certainty with some targeted investments.

Methods

The T-AGG literature synthesis summarized biophysical GHG mitigation potential for 43 agricultural land management activities. A smaller selection of these activities was chosen for further assessment of scientific certainty (Table 1). Activities excluded were those with no available data, negative net GHG mitigation potential, and low mitigation potential, as determined from the literature synthesis. Low national potential was defined as (1) applicability to < 25 Mha AND (2) an average mitigation potential < 1.0 t CO_2e yr^{-1} ha^{-1}. Therefore, some activities with relatively high potential but only regional applicability were included. These 28 activities were categorized into four related areas according to target GHG – (1) cropland soil C sequestration, (2) reduction of N_2O emissions, (3) CH_4 and multiple GHGs, and (4) grazing land management.

Once the topic areas were identified, a list of experts was compiled. All experts previously involved in the T-AGG project were included, and others were added on the basis of conversations with T-AGG stakeholders. Scientists were classified as experts using the following criteria: (1) PhD in soil science or related field, (2) 10+ years of experience in research, and (3) multiple publications in soil science, ecosystem science, agronomy, or related fields. A total of 60 experts satisfying these criteria were identified, sorted into one or more topic areas on the basis of their publication and research history, and invited to participate. A copy of the invitation letter can be found in Appendix A. The letter requested each expert to (1) indicate his or her willingness and availability to participate in the survey, (2) confirm topics of expertise, and (3) recommend any other experts not included in the original list. After the first set of expert responses, the list of experts grew to 81, leading to a second set of invitation letters.

Experts participating in the survey were top researchers specializing in GHG quantification and the impacts of agricultural land management activities on GHG fluxes. They included scientists from the United States and some from Canada and other countries, all with significant research and publication experience in agricultural land management and greenhouse gases. Each webinar treated a specific GHG mitigation category, so that scientists participated in webinars within their topic category of expertise. For example, only experts in soil C were involved in the assessment of C sequestration activities, and only experts in N_2O participated in the N management activity discussion and assessment. If an expert felt less than qualified to comment or register an opinion on a specific question, he or she could decline to do so.

The survey was run as five 90-minute webinars, during which up to six GHG mitigation activities were assessed. Scheduling was based on the experts' availability. A total of 33 scientists participated—some in more than one webinar. The number of participants in each webinar ranged from 5 to 14; the average was 10. In advance of each meeting, participants received materials explaining the webinar process and containing the relevant sections of the Synthesis Report.

The webinar software platform provided one-way visual communication and a linked conference call audio connection to participants. They could submit comments privately or to the group through a "chat" function. Individual "meeting rooms" could be created through a unique URL, which allowed for preservation of documentation for each meeting.

Table 1. Biophysical GHG mitigation potential of selected agricultural land management practices that were assessed for scientific certainty in experts' survey, as summarized from scientific literature. Values in bold were subjects of the certainty assessment.

Activity[a]	Soil C	In-field N_2O and CH_4	Upstream and process	Total GHG impact	Maximum area
	- - - - - - - - - t CO_2e ha^{-1} yr^{-1} - - - - - - - -				Mha
Switch from conventional to no-till	- -	-0.2	0.1	- -	72
Corn Belt, Lake States, South Central	***1.1***[b,c]	- -	- -	*1.0*	- -
Southeast	***1.7***[c]	- -	- -	*1.6*	- -
Great Plains	***0.4***[c]	- -	- -	*0.3*	- -
Pacific Northwest, Rocky Mountains	***0.8***[c]	- -	- -	*0.7*	- -
Switch from conventional to conservation tillage	**1.1**	0.1	0.1	1.2[d]	72
Use winter cover crops	**0.8**	0.3	0.6	1.7	74
Diversify annual crop rotations	**0.6**	0.1	0.0	0.6	99
Include perennials in crop rotations	**0.6**	0.0	0.2	0.8	56
Change from annual to perennial crops	**2.3**	0.1	0.5	2.9	13
Use short rotation woody crops (SRWCs)	**2.7**	0.8	0.7	4.1	40
Implement agroforestry (wind breaks, buffers, etc.)	**2.7**	0.8	0.4	3.8	10
Apply organic materials	**1.5**	0.1	0.9	2.5	8.5
Apply biochar	**3.4**	1.1	0.7	5.2	124
Convert cropland to set-aside	**2.5**	1.4	1.9	5.8	14
Reduce N fertilizer rates	- -	- -	- -	- -	124
In dry climates	*0.0*	***0.3***[c]	*0.1*	*0.3*	- -
In moist climates	*0.0*	***0.5***[c]	*0.1*	*0.5*	- -
Change fertilizer N source to slow release	0.0	**0.5**	0.1	0.5	93
Change N fertilizer placement	0.0	**0.3**	0.0	0.3	99
Change N fertilizer timing	0.0	**0.4**	0.0	0.4	62
Use nitrification inhibitors	0.0	**0.8**[c]	No data	0.8	99
Make irrigation improvements (e.g., drip)	0.4	**0.7**	0.2	1.2	20
Manage rice irrigation water (mid-season drainage)	0.0	**1.6**[e]	No data	1.6	1.3
Develop new rice varieties	0.0	**1.2**	0.0	1.2	1.3
Reduce rice acreage	Unknown	**4.8**	Unknown	4.8	1.3
Manage farmed histosols to reduce GHG emissions	**5.3**[c]	**11.2**[c]	0.0	16.5	0.8
Convert histosol cropland to set-aside	**28.5**[c]	**6.8**[c]	0.7	36.0	0.8
Restore wetlands	**3.7**[c]	**-1.4**	0.7	2.5	3.8
Convert cropland to pasture	**2.9**	1.0	0.5	4.3	Unknown
Improve grazing management, rangeland	**1.0**	0.3	No data	1.3	166
Improve grazing management, pasture	**2.9**	0.3	No data	3.2	48
Implement rotational grazing on pasture	**2.2**	0.1	0.0	2.2	42
Manage species composition on grazing land	**2.4**	-0.9	0.0	1.5	80

[a] Activities assessed in the Synthesis Report, but not included in the scientific certainty survey included (1) eliminate summer fallow, (2) switch from dry land to irrigated land, (3) reduce chemical use other than N fertilizer, (4) change N fertilizer source between common types, (5) improve manure management for N_2O emission reduction, (6) introduce rotational grazing on rangeland, (7) fertilize grazing land, (8) irrigate grazing land, and (9) convert pasture to ungrazed grassland. Reasons for these activities' exclusion from the survey included lack of data and negative or low national potential (<25 Mha of land AND <1 t CO_2e ha^{-1} yr^{-1}).

[b] Positive values indicate GHG mitigation (net soil C storage or reduced emissions of CH_4 and N_2O).

[c] Denotes values changed from the Synthesis Report (Oct 2010 version) due to updated information. For no-till and fertilizer N reduction, the target GHG values are separated into representative regions that exhibit noticeable differences in GHG mitigation potential.

[d] Row totals may not add up because of rounding.

[e] For rice water management, the total CH_4 mitigation potential is 2.4 t CO_2e ha^{-1} yr^{-1}. If this mitigation potential is combined with an increased possibility for N_2O emissions, the net GHG mitigation potential is 1.6 t CO_2e ha^{-1} yr^{-1}.

Each webinar began with an overview of the T-AGG project that emphasized the Synthesis Report review for the specified activities. Then the moderator clearly defined the survey objective: to assess the state of the science and thereby determine scientific certainty regarding existing GHG impact data. Participants were told that estimates of GHG mitigation potential were weighted average values for the entire United States and that these values could NOT be used as mitigation coefficients. However, the estimates were suitable for comparing the potential of different activities and for determining the activities that were most appropriate for further examination and refinement by region or other characteristic.

The question of scientific confidence focused only on the target GHG, and the activities were assumed to be technically feasible, with other conditions ideal (i.e., ignoring economic, technical, and social issues or barriers for the time being). For each set of activities, a set of qualifiers and caveats was established in discussion with all participants. Some, drawn from the literature, were suggested by the organizers before meetings; others were presented by participants during the discussion. Consensus was reached among participants after modifications and re-wording. Other considerations specific to each activity were established in the same manner. These qualifiers were recorded in real time and displayed directly on the slide presentation visible to all participants within the virtual meeting room. Discussion, debate, and rewording of the caveats occurred until all participants were in agreement. Only then did the webinar proceed to the voting segment for each activity.

For each activity, experts were asked to vote first on their *level of confidence* in the estimated mitigation potential derived from the literature review. The value was presented as in Table 1 with a range of ±20%.[1] The vote took place as an anonymous poll provided by the webinar software. Polls were created beforehand within the "meeting room" and displayed in sequence. Each participant had one vote, which could be anonymously submitted and changed as long as the poll remained open. The voting options and their definitions are outlined in Table 2. In a second vote for each activity, participants classified their opinion on the *level of evidence* available to support the estimated mitigation potential.

Table 2. Voting option definitions for levels of confidence and evidence related to GHG mitigation potential.

Vote option	Level of confidence	Level of evidence
High	Confident that the value is within the range given (i.e., ± 20% of the estimate)	Sufficient evidence in all applicable regions
Medium	Quite sure that the direction of the effect is correct (i.e., whether it increases or decreases emissions), but uncertain of the magnitude, pending further studies	Some regions or situations have sufficient evidence, but more is needed in others
Low	This is an educated, qualitative guess, based on scattered and incomplete data, but it seems reasonable (no directional certainty)	Evidence is scattered and incomplete
None	No confidence in the value	Not aware of any trustworthy evidence
Unknown	Unable to state an opinion	Unable to state an opinion

For each activity in sequence, the explanations of the voting options were clearly displayed in the virtual meeting room. The poll questions and options for answers were visible—without results—until all participants had voted, although the summarized results were available to survey facilitators. When the webinar moved to a new activity, the previous questions and answers were hidden. Once all activities within the session had been discussed, participants were given an opportunity to edit their votes in each poll (so that discussion on subsequent activities could be considered). After this point, voting was closed,

[1] An example of the statements presented for voting on confidence and evidence levels: "Conservation tillage has the potential to sequester soil carbon at a rate of 1.1 (± 0.2) t CO_2e ha^{-1} yr^{-1}."

and the results were displayed to all participants. Following the meeting, participants were provided with documentation of all caveats and voting results for the session.

Participants' vote responses were summarized and averaged, and *medium* or *high* confidence was deemed to constitute directional certainty (i.e., the scientists concluded that an activity *will* result in GHG mitigation). For level of evidence, *high* or *medium* results (if combined with *high* or *medium* confidence) indicate that scientific evidence is sufficient for incentivizing the activity, even though some regions may be excluded. In addition to the average results for each question, the level of agreement among participants was also noted. *High* agreement indicates that experts' responses were contained within two adjacent categories (e.g., high/medium OR medium/low). *Medium* agreement indicates that responses were within three categories (e.g., high/medium/low OR medium/low/none), leaving *low* agreement to indicate responses spread out within all four categories. Therefore, for each question we reported two characterizations of the response: the average "vote" and the variance of that answer.

Results

By indicating medium or high levels of confidence for almost half of the 28 activities surveyed, participating scientists expressed certainty in the potential to reduce GHG emissions or sequester C (Table 3a and Table 3b). The activities have been classified into four categories based on land management strategy and mechanism of emission reductions (i.e., C sequestration vs. N_2O emissions reductions). Detailed voting results are available in Appendix B. Of particular interest are the activities with low levels of evidence but positive directional certainty in the potential to achieve GHG mitigation (SRWCs, histosol management and set-aside, improved grazing management on pasture, and management of species on grazing land). For these activities, the mechanism for reduced net emissions are well-understood, and further movement toward including them in GHG mitigation projects or programs seems warranted, even without further research evidence.

The scientists indicated that evidence was insufficient to accord confidence in the capacity of some other activities to achieve GHG mitigation (these activities have low confidence and low evidence). For example, all N_2O emission reduction activities were deemed to have low confidence, mostly due to high variability in gas flux rates that lead to inconsistent impacts. For most activities with low confidence and low evidence, experts indicated that additional research data may improve scientific confidence. However, in one case, low evidence and low confidence also meant that scientists felt that the net GHG impact was unlikely to be positive, even with more research. Application of organic matter (most often manure), is unlikely to mitigate GHGs, because in most cases that matter would simply be moved from one location to another.

Those activities that involve land use change, yield decline, or a significant shift in agricultural product (e.g., grazing land instead of wheat) have the potential for leakage,[2] because agricultural production may move to another location. Leakage will often vary by the degree of change. For example, conversion from an annual to a perennial crop may elicit less leakage than conversion from cropland to set-aside. Throughout the survey, experts noted the leakage issues most likely to be problematic.

The remainder of this section is devoted to the individual activities included in the survey and presented within the four topic categories.

[2] Leakage refers to an increase in emissions as a result of the project activity that take place in a location outside the boundary of the GHG mitigation project. An example is a cropland set-aside that necessitates increased crop production—and results in increased GHG emissions—elsewhere.

Table 3a. Summary of results from survey of experts about scientific certainty. Green colors in the confidence column indicate directional certainty.

	Activity	Confidence	Evidence	Major issue
Cropland Soil Carbon				
	Switch from conventional to no-till*	Med	Med	
	Switch from conventional to conservation tillage*	Low	Low	Definitions for baseline and treatment are often unclear.
	Use winter cover crops*	Low	Low	Data, especially for some regions, are lacking; impact on main crop (and GHG implications) is unclear.
	Diversify annual crop rotations*	Low	Low	What is the baseline? Some diversification is not beneficial in terms of soil C.
	Include perennials in crop rotations	Med	Med	May be confounded with reductions in tillage.
	Change from annual to perennial crop*	Med	Med	Baseline and species need to be clearly indicated.
	Use short rotation woody crops (SRWC)	Med	Low	Variability in species and nutrient availability
	Implement agroforestry (wind breaks, buffers, etc.)	Low	Low	Lack of data
	Apply organic materials (especially manure)	Low	Low	Net GHG impact important to measure; could just be moving C from one place to another
	Apply biochar	No Vote	No Vote	Need life-cycle data for net GHG impact
	Convert cropland to set-aside	Med	Med	
Nitrous Oxide Emissions Reductions				
	Reduce N fertilizer rates (in dry climates)	Low	Low	Baseline emissions are low.
	Reduce N fertilizer rates (in wet climates)	Low	Low	Emissions (and reductions) vary by soil texture, irrigation status, etc.; need to address yield impact
	Change fertilizer N source to slow release	Low	Low	Lack of data, variable by climate
	Change N fertilizer placement	Low	Low	Interacts with tillage; varies by source
	Change N fertilizer timing	Low	Low	Lack of data
	Use nitrification inhibitors	Low	Low	Lack of data; varies by source
	Make irrigation improvements (e.g., drip)	Low	Low	Current lack of data, trade-off of direct and indirect emissions

* Denotes activities included in second cropland soil C session.

Table 3b. Summary of results from survey of experts about scientific certainty. Green colors in the confidence column indicate directional certainty.

Methane and Multiple GHGs				
	Manage rice irrigation water (mid-season drainage)	Med	Med	Multiple drainage events may enhance potential
	Develop new rice varieties	Med	Med	
	Reduced rice acreage	No Vote	No Vote	Not a credible option
	Manage farmed histosols to reduce GHG emissions (CO_2 emissions ONLY)	Med	Low	Need more data
	Manage farmed histosols to reduce GHG emissions (net N_2O and CH_4 emissions ONLY)	Low	Low	Need more data
	Convert histosol cropland to set-aside (CO_2 emissions ONLY)	Med	Med	Difficult to restore natural hydrology
	Convert histosol cropland to set-aside (net N_2O and CH_4 emissions ONLY)	Med	Low	Difficult to restore natural hydrology
	Restore wetlands	Low	Low	Variability in net GHG impacts
Grazing Land Management				
	Convert cropland to pasture	High	Med	
	Improve grazing management, rangeland	Med	Med	BMPs critical in drought years
	Improve grazing management, pasture	Med	Low	Need to define the baseline
	Implement rotational grazing on pasture	Low	Low	Need U.S. data
	Manage species composition on grazing land	Med	Low	Variable by species

Cropland Soil Carbon

The list of activities involving cropland soil C was the most extensive and was therefore addressed during two webinars. Across all of these activities, experts agreed that (1) estimates applied only to soil carbon (other GHGs are not addressed); (2) soil sequestration rates could be approximated by assuming a 20-year period of near-linear accumulation; (3) only biophysical potential is addressed, and all other factors are assumed to be optimal; and (4) variability across topography is high. The last two qualifiers were officially included in only the second webinar but can be assumed to be widely applicable.[3] Experts also noted that soil C sequestration rates would vary among regions, soil types, and environmental conditions. Caveats and qualifiers specific to individual activities are noted in the discussions of those activities.

Switch from conventional tillage to no-till systems

In no-till systems (also called zero-till or direct-drill), crops are seeded directly into the previous season's stubble, limiting soil disturbance to that occurring during planting. The experts' discussion of this activity focused first on the need for a solid definition of conventional tillage, which was determined to be mechanical tillage for primary weed control during the non-crop period. For soil C sequestration rates as

[3] Both of the last caveats, which were written down and approved during the second session, were discussed in the first session, but not officially noted. While technical potential was included in the introductory assumptions, participants in the second soil C session wanted it to be part of the written record. Activities that were included in the second cropland soil C session are noted with an asterisk (*) in Table 3a.

determined in the data synthesis, no-till is limited to continuous no-till, because future tillage may result in the loss of sequestered soil carbon. In addition, all other cropping system parameters must remain constant for the benefit to accrue to the change in tillage activity.

More side-by-side field comparison data are available for the switch from conventional tillage to a no-till system than for any other of the activities included in the survey. Therefore, we presented soil C sequestration rates for individual regions and gave participants the option to vote on confidence and evidence for each region. They chose to vote on all the regional estimates at once, because they deemed that the confidence and evidence ratings for each of the regions were similar. Very few data are available for California, and low soil C change potential plus negative yield impacts in the northeastern U.S. region led us to exclude these locations from the assessment. Given all the above caveats, the scientists concluded that moving from conventional tillage to a no-till system has positive potential to sequester soil C at rates of 1.1 (± 0.2) t CO_2e ha^{-1} yr^{-1} (Corn Belt, Lake States, and South Central), 1.7 (± 0.3) t CO_2e ha^{-1} yr^{-1} (Southeast), 0.4 (± 0.1) t CO_2e ha^{-1} yr^{-1} (Great Plains), and 0.8 (± 0.2) t CO_2e ha^{-1} yr^{-1} (Pacific Northwest and Rocky Mountains) (*medium confidence, medium agreement; medium evidence, high agreement*).

Switch from conventional tillage to conservation tillage

In this context, “conservation tillage” refers to any reduced-tillage practice other than no-till. The experts’ discussion focused on the need for specific definitions of conventional and conservation tillage, because varying definitions could significantly affect the observed rate of soil C change. They defined conventional tillage as mechanical tillage for weed control during the non-crop period, and conservation tillage as a tillage regime that maintains at least 30% residue cover on the soil after crops are planted. The experts expressed concern that application of these definitions is inconsistent in the current literature and that soil C impacts are more variable as a result.

Continuity of practice over time is of importance, because sequestered soil C could be lost under higher-intensity tillage in future years. In addition, other land management practices should remain consistent if soil C gains are to be attributed to the tillage change. The experts generally agreed that some regions (especially arid ones) may not experience positive C sequestration with conservation tillage, further contributing to their low confidence in that activity to achieve soil C sequestration (*low confidence, medium agreement; low evidence, high agreement*). However, the scientists felt that their confidence level could be increased if sufficient supporting data became available.

Use winter cover crops

Adding winter cover crops to a crop rotation can increase levels of soil C, and also reduce N_2O and fertilizer-related emissions. Cover crops are typically grown in combination with major grain crops such as corn, soybeans, and spring cereals to control nitrate (NO_3^-) leaching, provide nutrients (especially N) as “green manure,” conserve water resources, reduce insect and pathogen damage, and improve soil quality. Use of some species of winter cover crops is expected to be feasible in most areas of the United States, except in semi-arid regions, where soil moisture can limit crop growth. However, the lack of field data in many regions leads to low confidence for practical implementation. For example, what is the effect on harvest or planting schedules of the main crops? In drier regions, the net GHG impact may also be less positive if the cover crops increase irrigation demands.

Experts concluded that the GHG impacts of changes to the main crop (e.g., crop species or variety, or timing of seeding/harvest) need to be considered to ensure that emissions are not increased (or yield decreased) as a result of including a cover crop. The experts also noted that for GHG benefits to be credited to the winter cover crop, the tillage regime should be largely unchanged. The C sequestration rate may also depend on the cover crop species, especially whether it is an annual legume or a grass. Even with these qualifiers, the use of winter cover crops did not garner directional certainty in its potential to sequester soil C (*low confidence, low agreement; low evidence, high agreement*). There was general agreement that a lack of data is the main limiting factor.

Diversify annual crop rotations
Crop species can vary in growth patterns, biomass production, water requirements, and decomposition rates, all of which affect net GHGs. Therefore, the diversification of crop rotations with alternate species or varieties of annual crops may promote soil C sequestration, if associated with increased biomass or root exudates, or by somehow slowing decomposition. Crop rotation diversification most often involves moving from a continuously cropped cereal or simple rotation to multiple crops over multiple years of a crop rotation, and the most consistent soil C improvements have been noted where legume and non-legume crops are rotated.

However, experts noted significant variability among diversified crop rotation options; species (root productivity and residue amounts) and harvest intensity both play large roles in the net soil C impacts. If soil C increases are to be attributable to a diversified crop rotation, tillage regimes must not change and starting points must be specified (i.e., past management must be considered). Therefore, although the synthesized data presented an average of best options for crop rotation diversification, the resulting high degree of uncertainty and the need to select target rotations by region led experts to conclude that the evidence to support positive GHG mitigation potential for crop-rotation diversification was insufficient (*low confidence, medium agreement; low evidence, high agreement*).

Include perennials in crop rotations
Growing a perennial crop (often alfalfa or grass hay) for one to three years within an annual crop rotation (of a longer period) can significantly increase SOC levels. Perennial crops tend to reduce tillage disturbance; allocate a relatively high proportion of plant C underground; and demonstrate sustained root growth (as opposed to seasonal root growth that is characteristic of annual crops), thereby contributing to greater total primary productivity. With more evapotranspiration than annual crops, perennials can also decrease total moisture in the soil and thus reduce soil C decomposition rates. However, this characteristic also means that perennial crops may be limited in arid regions or irrigation requirements in such areas may increase GHG emissions.

The experts noted that species variability and differential root production also need to be considered, especially when grasses are compared with legumes or other types of perennial crops. The panel made the general assumption that, in a perennial/annual crop rotation, 50% of cropping seasons would be dedicated to perennial crops, as is typical for the Synthesis Report data. The inclusion of perennial crops in rotation has the potential to sequester soil C at a rate of 0.6 (± 0.1) t CO_2e ha^{-1} yr^{-1} (*medium confidence, high agreement; medium evidence, medium agreement*).

Change from annual to perennial crops
Switching from annual crops to perennials has a higher potential soil C sequestration rate than including perennials in an annual crop rotation. Even with removal of aboveground plant material, perennial systems can increase soil C because of their comparatively high belowground biomass productivity. Typical examples include legume or grass forages and perennials grown for biofuels production.

Arid areas are not considered here because irrigation requirements could offset any GHG mitigation gains. The experts also highlight that variability is affected by harvest intensity, crop type, and region (moisture and climate). Cropping history will also play a role in the soil C change. With these qualifiers, a complete change from annual to perennial crops was determined to have the potential to sequester soil C at a rate of 2.3 (± 0.5) t CO_2e ha^{-1} yr^{-1} (*medium confidence, medium agreement; medium evidence, high agreement*). This activity, therefore, has a high potential for GHG mitigation, even without including the possible fossil fuel offset of biofuels.

Use short-rotation woody crops (SRWC)
Planting of trees on agricultural or other non-forested land—"afforestation" (an official land use change from agriculture to forestry)—is considered a forestry activity only when rotations greater than 30 years. Short-rotation woody crops (SRWCs) are excluded from forest carbon management programs, and thus treated as an agricultural land management activity for this assessment, even though they tend to be different from most other agricultural crops—being perennials, but not providing food or forage.

Qualifiers associated with the soil C sequestration potential estimates for SRWCs include the definition of SRWCs as various woody species purposefully grown on former cropland in rotations of less than 30 years. The exact C sequestration potential will vary by species as well as water and nutrient availability. The panel emphasized that this potential refers only to soil C sequestration and not to aboveground and belowground biomass. Participants also noted that the sequestration rate would depend on the condition of the cropland to be planted in SRWCs (i.e., soil type and land use history are important). Given these caveats, SWRCs have the potential to sequester soil C at a rate of 2.7 (± 0.5) t CO_2e ha^{-1} yr^{-1} (*medium confidence, medium agreement; low evidence, high agreement*).

Implement agroforestry (windbreaks, buffers, etc.)
Agroforestry, the planting of trees among herbaceous crop plants, is most commonly implemented in the tropics, where the practice's productivity gains and C sequestration potential are often higher than those of other agricultural land uses. But agroforestry is also garnering some interest in North America. The few studies of agroforestry in the United States have reported significant soil C sequestration potential, but the paucity of data led the experts on the survey panel to ascribe low levels of certainty to those data (*low confidence, high agreement; low evidence, high agreement*). Overall the GHG impacts of agroforestry depend on the end use of the aboveground biomass and on the high variability in primary productivity (different species, regions, etc.). The experts also agreed that agroforestry's soil C sequestration depends on tree species, water and nutrient availability, and initial conditions (i.e. soil type and land use history). The discussion of soil C sequestration potential was limited to agroforestry on current cropland, in upland areas (excluding riparian locations), and applicable only to areas actually planted to trees (with no soil C impact on associated crop areas). Therefore, in addition to a general need for more soil C impact data, specific research needs include species variability in soil C sequestration rates, impacts on neighboring herbaceous crop area, and the differences between C sequestration in upland and riparian areas.

Apply organic materials (especially manure)
The United States produces a large amount of organic material, including livestock manure, municipal solid waste, and biosolids. Much of this material is already used to fertilize croplands and pasture, but its redistribution or redirection from landfills could increase soil C sequestration. The organic material most commonly applied to agricultural lands is animal manure, and the literature synthesis data comes entirely from manure application experiments. Although soil C sequestration estimates from the south-east averaged 0.7 t CO_2e ha^{-1} yr^{-1} greater than estimates from other regions, experts on the survey panel opted not to make this regional distinction.[4] They did note that soil type and texture, region, climate and water regime may affect soil C sequestration potential. For soil C increases from manure (or other organic materials) to be considered accrued C, the land must not be currently receiving manure or other organic amendments, and application rates must be at levels consistent with agronomic N and P application needs.

Even with these considerations, participants noted that virtually all manure is already applied to agricultural land, so any manure application on "new" land area could be simply moving the C source around the landscape and thereby achieving no real increase in SOC storage. For organic material additions to be considered GHG mitigation, a net improvement based on a full C balance of the entire

[4] The decision to consider all regions as one group in the panel's evaluation of organic material application owes largely to the fact that regional differences were overshadowed by concern that the activity may simply move carbon from one location to another.

system would need to be confirmed. The research reporting sequestration rates has not considered this issue sufficiently. True GHG mitigation could be achieved only if the decomposition rate of the material is affected (i.e., carbon is more stabilized if applied to a greater area or on different land). The soil C sequestration rate is also highly dependent on application rates and the quality of the material applied. Therefore, even though spreading manure on additional field locations has environmental benefits in terms of nutrient management, the soil C sequestration impacts are less certain. The panel concluded that there was no positive directional certainty regarding the potential of organic material application to sequester C in the soil (*low confidence, high agreement; low evidence, high agreement*).

Apply biochar

Biochar is produced by pyrolysis, the incomplete combustion of biomass into charred organic matter. Pyrolysis is used to capture heat and co-generate electricity as biofuel, but its end product can be used for soil application, potentially increasing soil C via three mechanisms: (1) storing recalcitrant C in biochar soil amendments, (2) stabilizing existing C in the soil, and (3) increasing biomass production aboveground, thereby increasing C inputs into soil. There are no U.S. field studies of the soil C sequestration potential of biochar application, only expert opinion based on calculations of available feedstock and expected C stability.

As with the application of manure, the panel of experts noted that anticipated sequestration rate per unit depends almost entirely on application rate, which could be highly variable. Therefore, potential mitigation rates expressed in units per hectare are not appropriate. Moreover, biomass availability and the soil C impact of removing the biochar feedstock from elsewhere is an important consideration. Therefore, biochar-related soil C sequestration can only be considered within a complete life-cycle analysis. Research suggests that the quality (and decay rate) of biochar is highly variable, being both process- and feedstock-dependent, and in some cases the relative decay rate of biogenic soil C versus char remains uncertain. Moreover, the application method (surface application vs. incorporation into the soil) can affect sequestration rates, and any productivity gains associated with biochar application may further confound GHG accounting. Therefore, with so few data available, the experts concluded that they did not feel comfortable voting on the use of biochar for GHG mitigation. The experts determined that the unanswered questions were significant enough that they needed to be addressed before any incentivization of biochar application for GHG mitigation.

Convert cropland to set-aside

Some cropland areas may have high potential for GHG mitigation when set aside, that is, converted back to “natural” or unharvested vegetation. “Set-aside” can take the form of herbaceous buffers (grass strips) within a field or along a riparian area, or comprise larger tracts of land. A significant amount of former cropland has already been set aside in the United States through the Conservation Reserve Program (CRP). The environmental co-benefits and non-GHG reasons for cropland set-aside are varied—wildlife habitat, erosion prevention, water quality protection, aesthetics. The GHG impacts of converting cropland to set-aside consistently include the potential for soil C sequestration and N_2O emission reduction. This survey addressed soil C sequestration only.

Research contributing to estimates of the biophysical soil C sequestration potential of set-aside generally considers only land where such conversion is economically feasible (and environmentally beneficial) – i.e., marginal agricultural land, often prone to erosion or flooding. This research is not applicable to histosols (“organic soils” with large proportions of organic matter rather than mineral fractions), which are addressed in a separate analysis because of their unique properties. Moreover, most research related to cropland set-aside deals with grassland rather than shrubs or forest. The expert panel concluded that there was positive directional certainty in the conversion of cropland to set-aside with the positive potential to sequester soil C at a rate of 2.5 (± 0.5) t CO_2e ha^{-1} yr^{-1} (*medium confidence, medium agreement; medium evidence, medium agreement*). Therefore, although perhaps limited in area (~14 Mha), this activity holds promise for inclusion in an incentive-based mitigation program.

Nitrous Oxide Emissions Reductions

Nitrous oxide is produced by two microbially mediated N processes—denitrification and nitrification. Rates of N_2O emission are positively correlated to concentrations of mineral N (ammonium [NH_4^+] and nitrate [NO_3^-]) in soil, although suitable C substrate and soil water content also play important roles. Thus, N_2O emissions from agricultural land are related to inorganic and organic nitrogen (N) fertilizer application, legume-derived N, and other factors that affect the availability of soluble mineral N in the soil.

For all N management activities, GHG emission reduction estimates are average responses over time, including any applicable "adjustment" period. Even with these average responses, there is high measurement variability at multiple scales; much of this variability is observed within the biological processes. N_2O fluxes are influenced by climate factors—especially rainfall, freeze/thaw cycles, and the depth of frost—and also by cropping variables (crop type, fertilizer rate), soil texture, and irrigation status. Agriculture also emits N_2O indirectly (from N lost by leaching or volatilization), but this assessment is limited to direct emissions only.

For all N_2O reduction activities, participants acknowledged that both measurement difficulty and the erratic nature of N_2O fluxes contribute to high variability and uncertainty in available data. Much of the available data are relatively recent, and focused in the north central United States, where N_2O emissions are often high immediately after the spring thaw. These data may therefore poorly represent other regions. The low certainties associated with N_2O reduction activities are largely a factor of this current paucity of good data and may change as more information becomes available. This webinar concluded with all participants agreeing that much research is needed.

Reduce N fertilizer rates

Field studies in cropland agriculture have found that emissions of N_2O tend to be correlated with fertilizer N rate. In general, higher rates of N application result in increasing N_2O emissions, but the functional relationship is not always consistent. If mineral N is the limiting factor for denitrification, N_2O emission rates rise in a nonlinear fashion (in relation to N application rate) when fertilizer rates exceed crop N needs, but this nonlinear response may not be observed if soil moisture or C substrate availability are limiting.

If N fertilizer rates are to be reduced to suppress N_2O emissions, little to no yield decline must occur. Experts deemed this caveat important, because crop production needed to ensure food security would otherwise shift elsewhere, perhaps increasing GHG emissions there. Therefore, N rates can be reduced if they now exceed an optimal rate, and improvements in N use efficiency will play an important role. Given data indicating lower total N_2O emissions—and correspondingly lower mitigation opportunity—in dry regions, the survey panel was given two estimates of N rate reduction for GHG mitigation: one for dry regions and one for moist regions. Participants felt the estimate calculated for dry regions was too high, and in fact there is likely to be limited gain in dry regions, where baseline N_2O emissions tend to be low. The results for dry and moist regions were similar (*low confidence, high/medium agreement; low evidence, high agreement*), indicating no directional certainty, given scattered and incomplete evidence.

Change fertilizer N source to slow release

Use of enhanced-efficiency N fertilizers (EEF), such as slow- and controlled-release fertilizers and stabilized N fertilizers, could enhance crop recovery of N and minimize N losses to the environment, both through leaching and N_2O emissions. Few long-term studies have investigated their effect on N_2O emissions, although some recent work suggests potential for coated and urea-based slow-release fertilizer to improve N use efficiency and to reduce N_2O emissions. The somewhat increased cost of production and transportation (due to this fertilizer's greater mass and bulk) may be justified by GHG benefits, efficiency gains, and water quality improvements.

The survey panel acknowledged that GHG mitigation benefits from a change in fertilizer type could be confounded by a rate change. However, given the lack of supporting field experiment data, they were not confident that this activity would generate emission reductions (*low confidence, medium agreement; low evidence, medium agreement*). The N_2O emission impact of slow release fertilizer in dry regions may differ from that in moist regions, but more research is needed to confirm the limited data.

Change N fertilizer placement
The placement of synthetic fertilizer near the zone of active root uptake may both reduce soil surface N loss and increase plant N use, reducing N_2O emissions. To that end, N fertilizer can be banded along crop rows or incorporated or injected into the soil. Another option is to modify the application rate for different areas of a field (e.g., using global positioning systems or other field area delineation) on the basis of yield expectations. Because plant N needs vary by yield, uniform N application can lead to over-application in low-yielding field areas. Banded placement may also reduce immobilization of N, delaying leaching or denitrification. The optimum placement for N fertilizer may vary by source, but experts assumed that there is no change in fertilizer source for this activity. Fertilizer N placement also interacts with tillage, and the resulting N_2O impact appears unclear in the literature (*low confidence, high agreement; low evidence, high agreement*). Further research could change the level of scientific certainty.

Change N fertilizer timing
Crop N uptake capacity is low early in the growing season, increases rapidly during vegetative growth, then drops sharply as the crop nears maturity. Synchronizing fertilizer N application with plant N demand may help reduce N losses, including N_2O emissions. Results from studies of split application during the growing season have varied, but lower emissions may occur, especially in areas with greater rainfall or irrigation. However, the literature on split application is sparse, and its results are often confounded by rate (i.e., rates are adjusted to account for improved timing). Timing changes can also include applying N fertilizer in spring rather than fall; several studies have measured lower N_2O emissions from this change. But again, fall N fertilizer is often applied at higher rates, and if lower N_2O emissions are to be credited to the timing change, the overall N rate must remain constant, yet optimal for the anticipated yield. Due to insufficient evidence and the confounding effect of rate, scientists had little confidence in the GHG mitigation potential of changing N fertilizer timing (*low confidence, medium agreement; low evidence, medium agreement*).

Use nitrification inhibitors
Nitrification inhibitors can significantly improve fertilizer N recovery and reduce NO_3^- leaching. By slowing nitrification, the release of soluble NO_3^--N is slowed, sometimes resulting in lower N_2O emissions, as observed in some studies. However, nitrification inhibitors do not affect NO_3^--based fertilizers, and the effects of fertilizer source need to be clarified. The use of nitrification inhibitors (*low confidence, medium agreement; low evidence, medium agreement*) has generally inadequate data with respect to N_2O emission impacts.

Make irrigation improvements (e.g., drip)
In general, irrigation reduces soil aeration and stimulates microbial activity, thus increasing the potential for N_2O emissions, but a reduction in irrigation intensity can decrease N_2O emission. By reducing the total amount of water applied and optimizing water distribution to root zones, irrigation efficiency gains can provide water (and energy) savings as well as direct GHG benefits. Many systems have moved from the less efficient furrow irrigation to the more efficient central-pivot sprinklers, further adoption of which may have some N_2O emission reduction effects. Even higher N_2O emission reductions have been seen with conversion from furrow- to drip- or subsurface-drip-irrigation, which requires 25% to 72% less water than furrow irrigation in agronomic and horticultural crops, with no negative yield impact.

Only direct N_2O emissions (on site) were considered in the discussion on irrigation improvements (*low confidence, medium agreement; low evidence, high agreement*). The experts noted that, if total losses remain the same, reducing direct N_2O emission reductions may increase leaching of NO_3^-, which can lead to off-site N_2O emissions. A number of the experts mentioned upcoming and new research on N_2O impacts of irrigation improvements (drip and buried drip irrigation) reported at the November 2010 Soil Science Society of America meetings. Experts felt that irrigation improvements, if validated through peer review and further testing, could be much better understood and their promise for reducing N_2O emission, confirmed.

Methane and Multiple Greenhouse Gases

Agricultural land management activities that could mitigate emissions of methane (CH_4) or multiple GHGs tend to apply to soils that were once flooded—whether in soil formation or historically (histosols and wetlands) or in current agricultural use (rice fields and some wetlands). In evaluating the GHG mitigation potential of these activities, the survey panel had two general caveats: (1) the activities must be compared to business-as-usual scenarios, and (2) both emissions and uptake must be quantified so that estimates reflect net GHG impact.

In the scientific literature, wetlands and histosols are somewhat confounded and a bit confusing. Histosols are a unique soil type. Unlike soils primarily made up of mineral particles (sand, silt, clay), histosols (organic soils) contain at least 20% to 30% organic matter—by mass—in at least the first 40 cm of depth from the surface. Many (but not all) organic soils (histosols) are also wetlands or were wetlands until drained for human uses. Some former wetlands available for restoration are not histosols, but the soils are composed primarily of mineral material. In identifying land management activities for GHG mitigation, histosols are separated from wetlands as a special case, to reduce variability and because there is somewhat more information available on GHG fluxes in histosols. Hence, "wetlands restoration" refers to all non-histosol water-influenced areas, even though the majority of the data came from the prairie pothole region. Currently cultivated histosols are significant emitters of CO_2 (via decomposition), and the GHG mitigation potential associated with their restoration is much greater than that for non-histosol wetlands.

Manage rice irrigation water (mid-season drainage)

Rice soils emit CH_4 because microbial respiration in flooded conditions reduces oxygen potential, creating anaerobic conditions that favor CH_4 production. While rice production is an important source of CH_4 worldwide, it accounts for only a small portion of total U.S. emissions. However, potential emission reduction per unit area is significant—in this assessment exceeded only by histosol set-aside—and U.S. research on management practices could guide development of GHG mitigation practices in other countries where rice systems are more prevalent. Mid-season drainage is one of the more promising CH_4-emission-reducing activities, although the biggest driver for mid-season drainage now is water conservation.[5] Such rice water management has the potential to reduce CH_4 emissions by 2.4 (± 0.5) t CO_2e ha^{-1} yr^{-1} (*medium confidence, medium agreement; medium evidence, medium agreement*) in regions that do not experience low night-time temperatures, which, when rice is not protected by flooding, can reduce crop productivity. The survey panel also noted that although single mid-season drainage has the potential to reduce CH_4 emissions by 50–60%, multiple mid-season drainage events could reduce emissions by 80–90%. Drainage may increase N_2O emissions in some cases (where soils have high organic matter content), but some experts noted that in their own experience in California, N_2O emission impacts were minimal.

Develop new rice varieties

High-yield cultivars can reduce emissions when compared with lower-yielding varieties, by directing more carbon to grain production rather than to root processes, where respiration results in CH_4 production. In development are also varieties that can grow under shorter flood periods (at least 30–40%

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[5] Reduced flooding time has very little impact on the water "consumption" of a rice crop, but it significantly reduces the amount of water that is "rented" (diverted from other purposes) for the growing season. There are some clear ecological benefits.

less flood time), reducing CH_4 emissions and saving water. The current literature is based on conventional practices, but the survey panel noted that new opportunities for GHG reduction seem likely in the development (currently under way) of dryland rice varieties (which are irrigated, but not left in flooded conditions), improved hybrids, and other prospects utilizing genetic modification (GM) or other biotechnology. These new opportunities and the high likelihood of near-term advances in rice variety development comprised much of the panel's discussion. As a result, the panel expressed confidence in the potential of variety development to reduce CH_4 emissions by 1.2 (± 0.2) t CO_2e ha^{-1} yr^{-1} (*medium confidence, medium agreement; medium evidence, medium agreement*).

Reduce rice acreage
Reducing the total area of rice grown in the United States may have the potential to decrease CH_4 emissions, but the survey panel concluded that it was not a credible option for a number of reasons. First and foremost, rice is an extremely important staple food crop, and with growing human population, reductions in rice production will negatively affect food security.[6] Second, any GHG emission reductions would depend on subsequent land use, and the net-GHG mitigation potential may not be as significant. This activity was thus removed from consideration (no voting).

Manage farmed histosols (organic soils) to reduce GHG emissions
In their natural state, especially if flooded, histosols emit CH_4 and sequester C in buried biomass, but net GHG flux varies. However, organic soils that are drained for agriculture emit significant amounts of CO_2 and N_2O, and they may become slight CH_4 sinks, turning farmed histosols into a significant GHG source, depending on practice, soil characteristics, and climate. Farmed histosols can be managed to reduce soil disturbance or maintain a higher water table, thus reducing organic matter decomposition rates (and CO_2 emissions).[7] This task can involve eliminating root crops in favor of crops needing less intensive tillage or converting annual cropland to grassland. The experts specifically noted that the upper Midwest histosols have different potentials for GHG mitigation than histosols in the California delta and Florida Everglades.

Because soil C (CO_2 emissions) and other land emissions (N_2O and CH_4) are all important factors in histosol management, experts assessed confidence in the literature's estimates for both GHG emission categories. Based on the evidence and their understanding of the relevant mechanisms, the scientists concluded that there was positive directional certainty in the potential of histosol management to reduce net CO_2 emissions by 5.3 (± 1.1) t CO_2e ha^{-1} yr^{-1} (*medium confidence, high agreement; low evidence, medium agreement*). However, with regard to other land emissions, they had more confidence in the capability of improved management to reduce CH_4 emissions than to reduce N_2O emissions, resulting in no net directional certainty (*low confidence, medium agreement; low evidence, medium agreement*). The lack of available data on the non-CO_2 impacts gave rise to this decision.

Convert histosol cropland to set-aside
The removal of histosol soils from agricultural production has the highest GHG mitigation potential per unit area compared with any other activity considered in this report. This comparative advantage is mainly due to significant reductions in organic matter decomposition (with associated CO_2 emissions). Net CH_4 emissions are expected to be highly variable, but N_2O emissions are most likely to decrease on conversion of histosol cropland to either grassland or natural ecosystems. Although elimination of field operations and fertilizer N may lead to upstream GHG emission reduction, production would likely shift elsewhere, so these benefits may not be realized when considering the entire agricultural production system. Other leakage concerns may also need to be addressed with this cropland conversion to set-aside.

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[6] Removing histosols from agricultural production did not elicit such a strong negative reaction, perhaps because the GHG impact of histosol set-aside was so significant and food production on these histosols could more easily be shifted to other farmland areas.
[7] Current CO_2 emissions are high in farmed histosols due to decomposition of the existing organic matter in the soils.

The set-aside of farmed histosols to natural conditions was split into two components so the survey panel could consider the data for soil C impacts separately from net reductions in N_2O and CH_4 emissions. Given the supporting data on this activity, the panel expressed positive directional certainty in the activity's potential to reduce CO_2 emissions by 28.5 (± 5.7) t CO_2 ha^{-1} yr^{-1} (*medium confidence, high agreement; medium evidence, high agreement*) and the potential to reduce N_20 and CH_4 emissions by 6.8 (± 1.4) t CO_2e ha^{-1} yr^{-1} (*medium confidence, high agreement; low evidence, high agreement*).

One of the caveats in the panel's consideration of conversion of histosol cropland was the assumption that natural hydrology is restored. The panel noted that managing the hydrologic cycle is difficult, and in some areas–especially the Florida Everglades, where much drainage has already occurred—it may not be possible. Thus, the opportunity to manage CH_4 emissions through water management may be a difficult task. Moreover, as with farmed histosol management, the experts noted that histosols in the upper Midwest must be considered separately from those in Florida and California.

Restore wetlands
Wetland restoration in this context is limited to non-histosols, which in North America can contain large amounts of stored C. These wetlands are highly variable in amount and characteristics of organic matter, drainage characteristics, vegetation, and other factors, and their natural processes are also dependent on temperature and salinity. Moreover, whether U.S. wetlands on the whole are net GHG sources or sinks remains unclear. However, in most cases, draining wetlands—often for agricultural purposes—changes the balance of emissions so that CH_4 emissions nearly cease and CO_2 emissions accelerate with very high soil organic C oxidation rates. Restoration of wetlands may reverse this effect. The GHG impacts of wetland restoration can be estimated by comparing the GHG balance of formerly cultivated land that has been restored with that of land still in cultivation. Due to lack of data and significant variability in the data available, the potential of wetland restoration to sequester soil C did not receive a vote of directional certainty (*low confidence, medium agreement; low evidence, medium agreement*). In fact, the panel noted that in tropical and mid-latitude locations, wetlands tend to be net GHG emitters and that only in some northerly locations (e.g., prairie potholes) should restoration of the natural system be considered for GHG mitigation. As with other cropland set-aside, leakage could be a concern.

Grazing Land Management

Grazing land can be divided into two classes with different productivity levels that affect soil C storage: (1) rangelands: uncultivated but extensively grazed land with minimal inputs, consisting of natural or naturalized plant species, and (2) pastures: more productive grazing lands characterized by intensive management and periodic agronomic inputs like cultivation, intentional species planting, irrigation, and fertilizers. Grazing lands in degraded or marginal condition will provide much greater soil C sequestration than highly productive, well-managed land with high current SOC levels. Therefore, the state of the range or pasture land before new management practices are implemented will determine soil C sequestration potential. One qualifier of this potential in the panel's discussion of grazing land management activities is that the soil C sequestration rate is the average over a 20-year time frame. One caveat was that, depending on environmental factors, the temporal variability of the activities' soil C sequestration potential may be significant.

Convert cropland to pasture
The conversion of annual cropland to grazed perennial grass/legumes (i.e., pasture) is very similar to cropland conversion to set-aside or other perennial crops, as discussed above. The main difference in terms of GHG impact is that the grazing animals (generally cattle) emit CH_4 as a result of enteric fermentation, thus affecting net GHG flux. Although this net impact may be an important consideration, depending on the relationship of livestock to the annual cropland system, only soil C was considered in the expert assessment. The conversion of cropland to pasture is included with other grazing land activities simply because grazing management is the context for soil C change.

For economic reasons (opportunity cost), conversion to pasture tends to be limited to marginal cropland, where it can also reduce soil erosion on previously eroded uplands and sideslopes and impose fewer field implement constraints in poorly drained depositional areas. The survey panel asserted that conversions need to be permanent to attain the full soil C sequestration benefit. Complete baseline assessments of vegetation and soil condition are necessary, and the resulting pasture management must utilize best practices. Given these caveats, conversion of cropland to grazing land has potential to sequester soil C at a rate of 2.9 (± 0.6) t CO_2 ha^{-1} yr^{-1} (*high confidence, high agreement; medium evidence, high agreement*). Given that a reasonable amount of data are available, the panel felt the underlying mechanisms were well understood. Their high confidence level indicates not only positive directional certainty, but also support for the average soil C sequestration rate being within 20% of the average value drawn from the literature.

Improve grazing management on rangeland

Compared with more productive pasture, rangelands have lower C sequestration rates, but their vast area increases their total national GHG mitigation potential. Grazing practices are central to healthy rangeland management, and excess grazing can decrease soil C storage. Well-managed grazing facilitates root and shoot decomposition to soil organic C through removal of aboveground biomass and the churning of surface soil by animal hooves. Removal of excess aboveground material also regenerates root growth and hastens the onset of spring re-growth and photosynthesis. Unlike removal for hay, grazing returns the majority of nutrients back to the soil through excreta. Improved grazing management on rangelands (appropriate stocking rate/forage utilization, timing of grazing to avoid the months of high C uptake, and adjusted frequency of grazing) has the potential to sequester soil C at a rate of 1.0 (± 0.2) t CO_2 ha^{-1} yr^{-1} (*medium confidence, high agreement; medium evidence, high agreement*). To realize this potential, the baseline management and soil condition need to be carefully defined, because the potential for soil C sequestration tends to be greater on rangeland that is now poorly managed. Good management during drought years is especially critical. Due to a lack of data, the survey panel did not consider shrublands.

Improve grazing management on pasture land

For pasture, a promising C sequestration practice is improved grazing management (which, as for rangeland, often but not always involves reducing stocking rates).[8] Pasture land tends to yield greater net primary productivity—and thus higher soil C sequestration rates—than rangeland. As on rangeland, grazing management on pasture is assumed to have very little N_2O effect; CH_4 emissions are affected primarily by enteric fermentation and thus by grazing intensity. Although it is an improved practice, rotational grazing is considered separately. As is the case with improved management on rangeland, a comprehensive definition of the baseline soil conditions and vegetation is required, and best management practices are critical during drought years. Improved grazing management on pasture has the potential to sequester soil C at a rate of 2.9 (± 0.6) t CO_2 ha^{-1} yr^{-1} (*medium confidence, high agreement; low evidence, high agreement*). The survey panel had confidence in the mechanism, even though field data are lacking.

Implement rotational grazing on pasture

Rotational grazing (also known as management-intensive grazing, MIG) differs from continuous grazing in that land is divided into small paddocks, among which animals are regularly moved. This practice reduces the period of grazing pressure (e.g., to 1–3 days for ultra-high stocking density or 3–14 days for typical rotational grazing), allowing land a rest period for re-growth. On highly productive pasture, rotational grazing maintains the utilized forage at a relatively young and even growth stage, allowing cattle to access better-quality, lower-fiber-content forages. In this way, rotational grazing lowers CH_4 emissions from grazing animals by up to 22% when compared with continuous grazing. MIG has been promoted and assumed to be superior to continuous grazing in terms of productivity, which may translate to C sequestration potential and might also allow shifts of pasture land to afforestation or other high C sequestration activities.

[8] A reduction in stocking rates could result in lower beef "yield" per unit area and thus have implications for food security and for leakage (i.e., animal production would likely be moved to another location, which might experience increased GHG emissions).

However, the experts were unaware of any studies that estimated the GHG impacts of rotational grazing in the United States, so they expressed little certainty in the activity's soil C sequestration potential (*low confidence, medium agreement; low evidence, high agreement*). Although there are indications of soil C sequestration from rotational grazing on pastures in New Zealand and Australia, they may not be applicable to U.S. pastures, which have lower seeding rates and less diverse species mixes as well as differing in other characteristics. The experts raised questions about how stocking rate could be captured and how rotational grazing's impact on soil C might differ in mixed species versus monoculture pastures.

Manage species composition on grazing land
Although grazing management itself can affect the forage species mix, all data to support direct management of species composition were drawn from experiments in interseeding—i.e., introducing desirable species. Species composition can serve an important role in C sequestration on both rangeland and pasture, and seeding or interseeding desired species can increase net primary productivity and improve forage quality. Additional considerations raised by interseeding include potential emissions associated with its soil disturbance, evidence of enteric emissions reductions from cattle on grass/legume pastures compared with cattle on pure grass stands, and lower N_2O emissions from legumes compared with grasses. Experts determined that there was positive directional certainty in the potential of interseeding/seeding to sequester soil C on grazing land at a rate of 2.4 (± 0.5) t CO_2 ha^{-1} yr^{-1} (*medium confidence, medium agreement; low evidence, high agreement*).

Discussion

The findings of this survey can serve two useful purposes in the effort to include U.S. agricultural land management in GHG mitigation. First, activities with medium and high levels of scientific confidence can be prioritized for early inclusion in programs or projects, given that their provision of environmental benefits is assured. Second, activities in which scientific confidence is lacking primarily as a result of little physical evidence can be prioritized for near-term research, which can address specific data gaps and bolster confidence.

Table 4 lists all 13 activities in which the survey panel expressed positive directional certainty in GHG mitigation. The table notes each activity's expected average mitigation potential and applicable U.S. area. The GHG mitigation processes of these activities are reasonably well understood in the scientific community, even though additional data would often help reduce uncertainty.[9] The activities with the greatest GHG mitigation potential nationwide include use of no-till systems, introduction of short-rotation woody crops, pasture and rangeland grazing management, and grazing land species management. While perhaps less important nationally, the other activities that have lower potential per unit area or smaller applicable area are likely to find a place within an incentive-based program, especially if they are cost-effective. These activities include converting histosol or other sensitive cropland to set-aside, including perennials in crop rotation, moving from an annual to a perennial crop, managing histosols for GHG emissions, managing rice irrigation water, developing rice varieties, and converting cropland to pasture.

[9] For example, use of short-rotation woody crops, improved grazing management on pasture land, and management of the species composition of grazing lands were ranked low with regard to level of evidence, but deemed to have medium confidence..

Table 4. Activities with positive directional certainty for GHG mitigation potential (≥ medium level of scientific confidence).

Activity	Total GHG impact ($t\ CO_2e\ ha^{-1}\ yr^{-1}$)	Maximum applicable area (Mha)	Comments and considerations
Switch from conventional tillage to no-till systems	1.0 (range from 0.3 to 1.6)	72	Significant regional differences in physical potential (and also economic/technical applicability)
Include perennials in crop rotations	0.8	56	Species selection is a key factor
Change from annual to perennial crops	2.9	13	Species selection is a key factor; leakage may be a concern
Use short-rotation woody crops	4.1	40	Net GHG impacts from choice of end-use should also be considered; leakage issues could be significant
Convert cropland to set-aside	5.8	14	Leakage issues may negate some benefits, especially upstream and process impacts, which would move elsewhere
Manage rice irrigation water (mid-season drainage)	1.6	1.3	May have N_2O emission effects; need to consider night-time temperatures
Develop new rice varieties	1.2	1.3	Could also have water-saving potential
Manage farmed histosols (organic soils) to reduce GHG emissions	16.5	0.8	
Convert histosol cropland to set-aside	36.0	0.8	Applicable to a small area of land, some of which is highly productive; leakage issues
Convert cropland to pasture	4.3	Unknown	
Improve grazing management, rangeland	1.0	166	More potential on poorly managed land; leakage issues with stocking density change
Improve grazing management, pasture	3.2	48	
Manage species composition on grazing land	1.5	80	VERY limited data on N_2O and CH_4 impacts; needs more research

Lack of scientific evidence did not always result in low scientific confidence in an activity's GHG mitigation potential, indicating that a clear understanding of the processes involved can in some cases substitute for data. Therefore, well-designed and calibrated models can be particularly useful in GHG mitigation programs. On the other hand, all activities with low levels of scientific certainty were also associated with a lack of scientific evidence, necessitating additional data collection.

Cropland Soil Carbon

With respect to cropland soil C impacts, all five activities with positive directional certainty[10] exhibit similar underlying mechanisms for soil C sequestration: tillage reductions, increases in biomass productivity, or both. Increased understanding of the biomass production and decomposition processes could enhance scientific certainty in activities promoting similar impacts, such as agroforestry and conservation tillage. Conservation tillage may have applicability, especially where no-till systems are constrained by soil moisture or other issues, making greater understanding of the soil C response to different levels of tillage a high research priority. By also paying attention to species, climate, and other factors, scientists can better understand soil C sequestration processes and identify the best opportunities for GHG mitigation. The research needs for diversifying annual crops and using winter cover crops are similar; in these cases special attention is also needed with regard to species selection, timing, tillage, and harvest intensity. However, with few field data available for winter cover crops, this may merit high

[10] These five activities are: (1) switch from conventional to no-till systems, (2) include perennials in crop rotations, (3) change from annual to perennial crops, (4) use short-rotation woody crops, and (5) convert cropland to set-aside.

research priority, especially because they also have the potential to reduce N fertilizer requirements and could be grown over large areas of U.S. cropland.

Data needs with respect to the remaining two activities that affect cropland soil C are complex. To assess the mitigation potential of both biochar and organic material (manure) applications, scientists require comprehensive life-cycle analyses that incorporate feedstock availability, process emissions, application rates, and productivity gains. Net soil C sequestration over the entire landscape from source to application area must integrate the effects of the diversion of materials from previous application areas. The possibility of significant soil C sequestration with biochar and organic material applications increases the importance of near-term research on both these activities.

Nitrous Oxide Emissions Reductions

All N_2O reduction activities addressed in the survey generated results of *low confidence* and *low evidence.* At least some scientists on the survey panel concluded that, with the exception of N application rate adjustments, they had *no* confidence in the potential of these activities to mitigate GHG emissions and that they were unaware of *any* trustworthy evidence to support GHG mitigation by the activities. This was largely related to the fact that the implementation of these placement, source, and timing activities tend to affect N use efficiency, and thus the rate of application. It is therefore difficult to determine to which activity to attribute any GHG mitigation benefit. Of note are the ongoing benefits of N_2O emissions reduction (no "saturation" point, as in C sequestration) and the large area over which the activities are applicable. Consequently, any N management improvements could have significant potential for GHG mitigation.

The focus of the survey was the available scientific data, and one of the major issues raised during the survey discussion was the difficulty of obtaining very precise data for N_2O gas fluxes. However, experts noted that new data on this topic are forthcoming (much of the relevant research has only been performed within the past ~10 years) and that it may be possible in the interim to provide forecasts of likely mitigation scenarios through various biogeochemical models (e.g., DNDC or DAYCENT),[11] even though the accuracy of existing data affects the accuracy of models. As models are continually updated, verified, and calibrated, the expectation (hope) is that the results will increase certainty about the mitigation potential of applicable activities. Moreover, the accuracy of these predicted values will increase as models take into account variables like local climate and rainfall, crop system details, water table levels, and soil characteristics. When applied at a larger scale (both time and area), models can be expected to enhance accuracy and to predict and monitor N_2O flux impacts.

Methane and Multiple GHGs

With significant potential to reduce CH_4 emissions in the United States and to inform similar efforts overseas, both rice water management and rice variety development have positive directional certainty and medium levels of evidence. Therefore, these activities look promising for inclusion in an incentive-based program. Further research into the net GHG impacts of histosol management appears to be necessary. The experts agreed that CO_2 emissions were certain to be reduced, but they were uncertain about net N_2O and CH_4 impacts. Given such high potential for emission reductions (even though in a small area), these impacts may be a high-priority area for research.

Grazing Land Management

Four of the five grazing land management activities have positive directional certainty for GHG mitigation, but conversion of cropland to pasture was the only activity in the survey to garner high

[11] A comprehensive examination of these models can be found in the companion T-AGG report "Comparison of Three Biogeochemical Process Models for Quantifying Greenhouse Gas Effects in Agricultural Management."
http://nicholasinstitute.duke.edu/ecosystem/t-agg/comparison-of-three-biogeochemical-process-models-for-quantifying-greenhouse-gas-effects-of-agricultural-management

scientific certainty, meaning that the estimated soil C sequestration rate of 2.9 t CO_2 ha^{-1} yr^{-1} is likely accurate within a range of 20%. This result is somewhat curious, because the mechanisms contributing to that activity's soil C sequestration are the same as those for cropland set-aside and conversion to perennials. High confidence in cropland-to-pasture conversion but only medium confidence in the other two related activities may be an artifact of the participation of different scientific experts in the different survey groups, or it may reflect differences in the research (and confidence therein) from which the estimates are drawn. Pastures may be more uniformly defined than cropland set-aside, resulting in higher confidence in the soil C impacts of cropland-to-pasture conversion. In addition, applicable land (and the focus of data) for cropland set-aside is sensitive to erosion or flooding and therefore may be less productive than the land often used for cropland-to-pasture conversions. Moreover, the soil C impact depends on the choice of plant species. For conversion to grazing land, the species chosen will be highly productive and thus may provide more consistent soil C accrual than species chosen for cropland set-aside and conversion to perennials.

The other three activities garnering directional certainty in the category of grazing land management have similar mechanisms for soil C sequestration. Best management practices on pasture and rangeland are designed to increase primary plant productivity and minimize soil erosion and compaction through the growth of healthy root systems (belowground biomass). Species management (interseeding) accomplishes similar goals.

Rotational grazing may suffer from definition-based problems similar to those encountered in the experts' assessment of conservation tillage. Moreover, the effects of independent variables like stocking rate and species composition on GHG mitigation potential need to be understood before rotational grazing can be included in an incentivized program. The high potential for soil C sequestration noted in areas other than the United States suggests that rotational grazing (on productive pastures) deserves a closer look as a potential GHG mitigation activity.

Conclusions

T-AGG used a survey of experts to assess the scientific confidence associated with the GHG mitigation potential of 28 activities that have been assessed for their inclusion in incentive-based projects and programs applicable to U.S. cropping and grazing systems. By identifying activities for which expert scientists ascribed confidence in GHG mitigation achievement, the survey results indicate the activities that are most appropriate for additional review and possible early inclusion in market or regulatory programs. Caveats and qualifiers for each activity highlight key issues to consider during project or program design and implementation.

Thirteen of 28 activities elicited positive directional certainty. Some of these activities were deemed to have sufficient evidence of GHG mitigation potential in the scientific literature, at least in certain regions, but for other activities, the evidence is incomplete. Where there was scattered evidence but positive directional certainty, experts felt they had sufficient understanding of the biogeochemical processes to express confidence in GHG mitigation potential, making these activities likely candidates for more detailed assessment before inclusion in incentive programs or projects.

All activities in which the experts expressed low confidence in GHG mitigation potential were also activities associated with a lack of supporting research. However, experts asserted that some of these activities are high priorities for research (e.g., N_2O emissions reduction opportunities and rotational grazing on pasture) because they may have significant potential for GHG mitigation, even though at this point the data are uncertain. Therefore, in these cases where additional research could improve confidence, the survey results could be used to target limited research funds toward the most beneficial or promising areas.

Appendix A: Invitation Letter

Dear Dr. XXXX,

The Technical Working Group on Agricultural Greenhouse Gases (T-AGG) is compiling scientific and technical background information to inform project and program implementation of agricultural GHG mitigation activities, with a focus on land management. Part of this work includes determining the level of scientific certainty associated with biophysical mitigation potential estimates derived from the peer-reviewed literature. These estimates are meant to give programs and policy makers a sense of where the greatest opportunities exist for agriculture's contribution to GHG mitigation, and to determine whether existing data is sufficient for parameterization and calibration of biogeochemical process models.

Following our in-depth literature review and synthesis, we are conducting a survey of experts to obtain measures of confidence in the resulting values. The goal is to gain a qualitative understanding of scientific certainty for GHG mitigation potential of various agricultural activities. We are NOT seeking to calculate a national emissions factor.

Since you have been identified as an expert in the field, we would value your participation in this survey. There will be four major topic areas, each with a separate survey: (1) soil carbon management (on cropland), (2) nitrous oxide emissions reduction, (3) grazing land management, and (4) methane or multiple GHGs (includes wetlands and rice).

We have noted your expertise in [indicate expertise here]. If you feel confident/competent in one or more of the other topic areas listed above (or if you feel we are in error), please let us know by response to this message.

The survey will be run as a 90-minute webinar-style conference call. During the webinar, you will be asked to discuss and comment on the scientific certainty associated with GHG impact estimates (drawn from a literature review) of five or six specific agricultural land management activities. We will provide the literature synthesis section for each relevant activity a few days prior to the survey. (For more information see the literature synthesis report at http://nicholasinstitute.duke.edu/ecosystem/t-agg.)

We will begin the survey on or around November 8, 2010, and complete the process by November 18, 2010. If you are able to participate, please complete the scheduling poll at the following website address [doodle survey]. We will then contact you directly to schedule your survey webinar(s).

To ensure the best possible results, we want to survey a balanced group of experts, including the most informed and well-respected within the fields of study in the United States. Please see the attached “List of Experts” and suggest additional names of people we should contact. You may enter these names into the comment field at the bottom of the scheduling poll or send them by email in response to this message.

To summarize, please:

1. Indicate your availability to participate using the scheduling poll.
2. Tell us if we should modify the relevant topic areas we’ve indicated for you.
3. Suggest additional people for this survey of experts.

Thank you for your consideration, and we look forward to hearing from you soon.

Sincerely,

Samantha Sifleet, Research Assistant

Alison Eagle, Research Scientist

Nicholas Institute for Environmental Policy Solutions, Duke University

Appendix B: Survey Data

Table B-1. Qualifiers and caveats for GHG mitigation activities, verbatim from webinar sessions

Soil C Management	
• Assume 20-yr period of near-linear C sequestration • Addressing C only • Technically feasible soil C sequestration, assuming other conditions (i.e., economic, social, leakage) are ideal; thus also assuming no reversals • Highly variable by topography*	
Conventional to no-till*	• Exclude northeast region of U.S. from national average value (only 4% of area), due to low potential for soil C change and negative yield impacts – all literature review data based on Ontario and Quebec • Exclude California – no data • Clearly set definition for conventional tillage – mechanical tillage for primary weed control (in non-crop period) • Must be continuous no-till • Loss of C when tilled in future • Assumes no other change in cropping system
Conventional to conservation tillage*	• Conventional tillage – mechanical tillage for primary weed control (in non-crop period) • Conservation tillage maintains at least 30% residue cover on the soil surface after planting • Loss of C when tilled at greater intensity in future • Assumes no other change in cropping system • Rate may be lower for semi-arid regions
Use winter cover crops*	• Only in regions where cover crops can be implemented • Also need to consider changes made in main crop (variety, timing, etc.) to accommodate the cover crop – soil C impacts? • Assume same tillage regime
Diversify annual crop rotations*	• Species variability • Largely a factor of amount of residue and root productivity • Dependent on harvest intensity • Assume similar tillage regime • Need to specify starting and end point • Average of best options
Include perennial crops in rotations	• Problematic in arid regions (irrigation needs) • It can be difficult to separate the impact of crop changes from tillage-reduction effects • Assume 50% of cropping seasons in perennial crop. • Variability by species (e.g., diff. root production)
Change from annual to perennial crop*	• Exclude arid areas • Dependent on harvest intensity and crop type (both the cropping history and the selected perennial crop) • Dependent on region (moisture and climate)
Short-rotation woody crops (SRWC)	• Purpose-grown on former cropland, various woody species • Rotations are less than 30 years • Soil C impacts only • Depends on the species – research needs to differentiate • Depends on other nutrient or water availability characteristics
Agroforestry (windbreaks, alley cropping, etc.)	• Sequestration applies to area in trees; assumes no impact on field crop area • SOC only; does not include aboveground and belowground biomass • Depends on the species – research needs to differentiate • Depends on other nutrient or water availability characteristics • Depends also on starting conditions: soil type, land use history • Starting with cropland • Applying to upland agroforestry only (riparian should be considered separately)

Application of organic materials (e.g., manure)	• Literature synthesis primarily manure • Assumes application on land not currently receiving manure or other organic amendments • Assume manure applied for N and/or P agronomic rate • Full C balance accounts for area that no longer receives the manure • Need regional, soil type, climate, and water regime differentiation
Biochar application	• Estimate is based on expert opinion alone • GHG impacts of productivity gains are not included in this estimate • Quality of biochar can be highly variable • Dependent on the amount of biochar applied to the soil • Need to consider application process (surface vs. incorporated) . • SOC sequestration rates need to be considered in the context of the full long-term life-cycle analysis – how else would biomass source be used (is it a net gain)? • **No vote**
Cropland to set-aside	• Sensitive land prone to flooding or erosion (focus of research in literature) • Does not include histosols
Nitrogen Management (N_2O emission reductions)	
• Estimates are average responses over time, including any applicable "adjustment" period • High measurement variability at multiple scales • Variability due to climate – especially consider rainfall, freeze/thaw cycles, depth of frost • Significant dependence on cropping system (crop type, fertilizer amt.) • Need to consider soil texture and irrigation status • Not considering indirect N_2O emissions	
Reduce N fertilizer rates	• Research studies assumed little or no yield decline
Change fertilizer N source to slow release	• Assuming no change in rate
Change N fertilizer placement	• Optimum placement may depend on fertilizer source • Assuming no change in source • Can include incorporation, banding, injection
Change N fertilizer timing	• Can include moving from fall to spring application • Also includes split applications (pre-plant and/or within growing season) • Assuming rate remains the same – optimum rate for anticipated yield
Use nitrification inhibitors	• Need to clarify impact by fertilizer source • Does not apply to nitrate-based fertilizers
Irrigation improvements (e.g., drip)	• Drip is an improvement over furrow irrigation • Can be a trade-off of N_2O emission reduction versus NO_3 leaching reduction • Direct emissions only
Methane and Multiple GHGs	
• Emissions and uptake are both quantified – net GHGs • Comparing activity with business as usual	
Rice water management (mid-season drainage)	• Impacts on N_2O may also be important (at least in soils with higher SOM) • Multiple drainage events can have significantly higher potential
Rice variety development	• Related to an increase in grain yield • Related to flood period – some hybrids can reduce flood period by 30-40% • Include advancements by GM and biotechnology • Literature is based on conventional practices – dryland rice or other advancements could have much higher potential
Reduced rice acreage	• Dependent on subsequent land use – food production, leakage, etc. • **Eliminated – not a viable option**
Manage farmed histosols (organic soils) to reduce GHG emissions	• Includes changing from root crops to those needing less intensive tillage • Plus other reductions in tillage • Also converting to grassland • Managing for high water tables • Upper Midwest should be considered separately from California and Florida
Convert histosol cropland to set-aside	• Leakage is a concern – production moving elsewhere

	• Upper Midwest should be considered separately from Florida and California • Assumes restoration of natural hydrology
Wetland restoration	• Can also increase CH_4 emissions, accounting for up to half of soil C GHG impacts • Leakage is a concern – production moving elsewhere • Some wetlands are net GHG emitters – high variability, related to temperature • Restoration process only in first period of time – then net emission of GHGs more likely to follow
Grazing Land Management	
• Average soil C sequestration rate expected over 20-yr time frame • Temporal variability can be significant, depending on environmental factors	
Convert cropland to pasture	• Baseline management (including vegetation) and soil condition need to be carefully defined • Assumes marginal cropland converted to grazing use • Pasture management needs to be defined (well-managed) • Assumes conversion to permanent perennial pasture
Improved grazing management, rangeland	• Baseline management (including vegetation) and soil condition need to be carefully defined • Good management during drought years is especially critical • Due to lack of data, this assessment excludes arid shrublands
Improved grazing management, pasture	• Baseline management (including vegetation) and soil condition need to be carefully defined • Good management during drought years is especially critical • Excluding rotational grazing
Rotational grazing on pasture	• Dependent on stocking density and stocking rate and rotational intensity
Manage species composition of grazing land	• Studies considered are seeding and interseeding efforts (grazing-induced species compositional changes are included in "grazing management," above)

*Denotes caveat or activity included in second soil C management webinar.

Table B-2. Key to colors for voting results in the following figures.

	Confidence	Evidence
High	Confident that the value is within the range given	Sufficient evidence in all applicable regions
Medium	Directional certainty, but uncertain of the magnitude	Some regions or situations have sufficient evidence, but more is needed in others
Low	No directional certainty	Evidence is scattered and incomplete
None	No confidence in the value	Not aware of any trustworthy evidence
Unknown	Unable to state an opinion	Unable to state an opinion

Figure B-1. Survey voting results for cropland soil C. The top bar for each activity represents the vote on confidence data, and the bottom bar, the vote on evidence. See Table B-2 for explanation of voting categories.

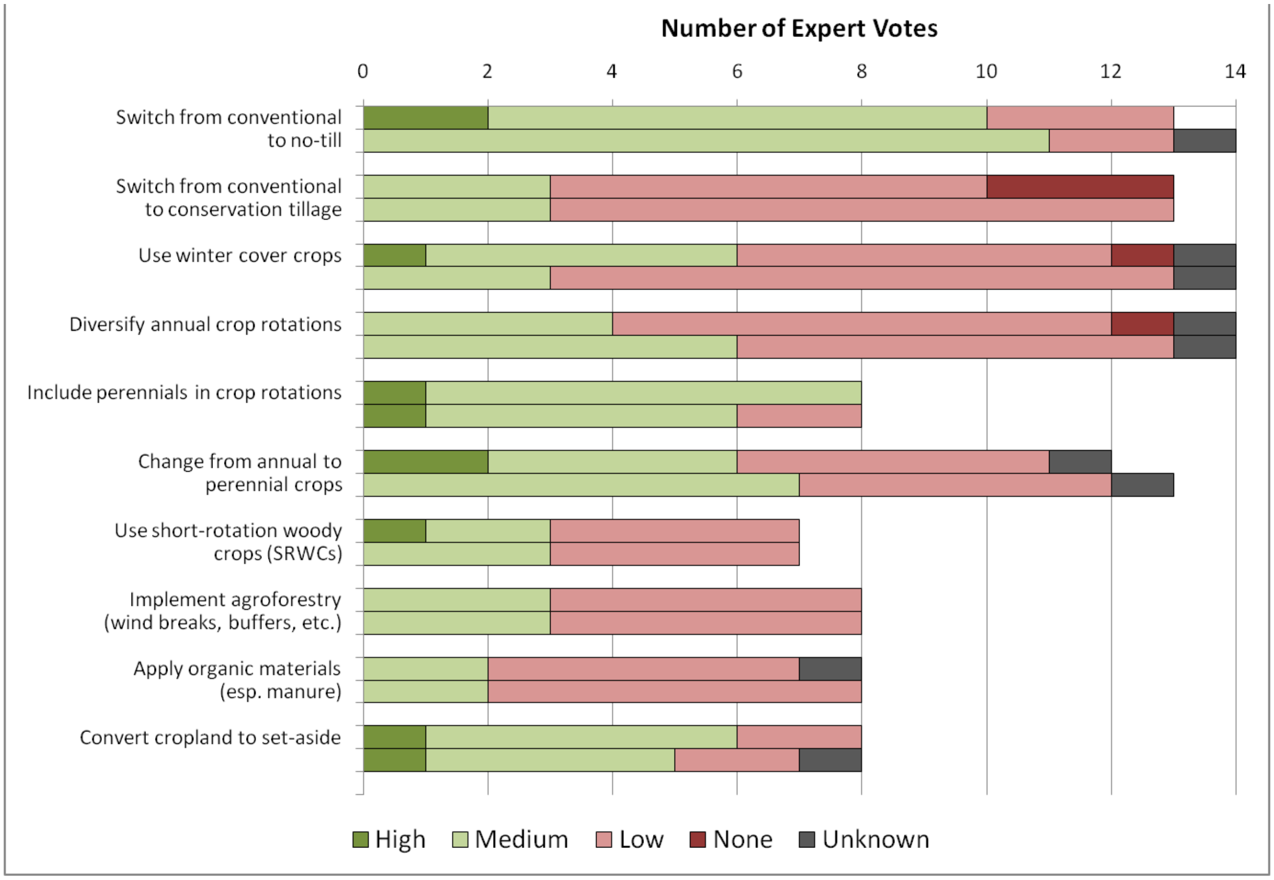

Figure B-2. Survey voting results for activities affecting N_2O emissions reductions. The top bar for each activity represents the vote on confidence data, and the bottom bar, the vote on evidence. See Table B-2 for explanation of voting categories.

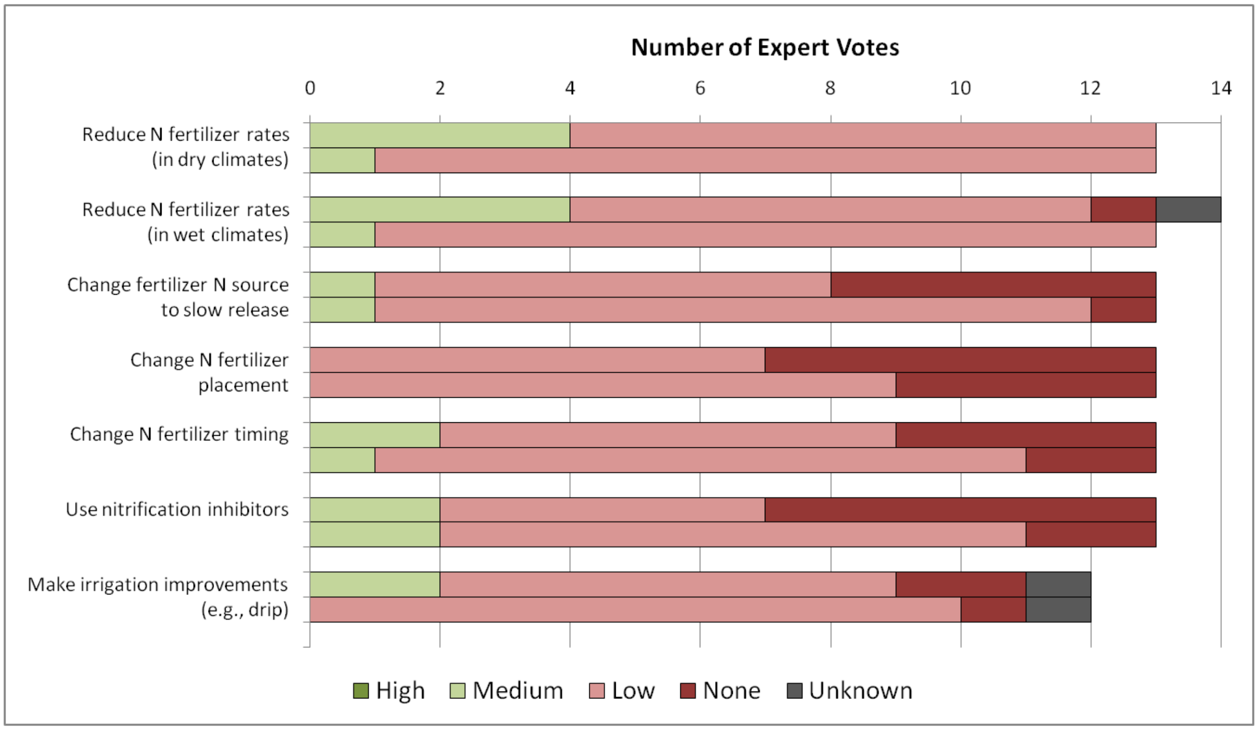

Figure B-3. Survey voting results for grazing land management activities. The top bar for each activity represents the vote on confidence data, and the bottom bar, the vote on evidence. See Table B-2 for explanation of voting categories.

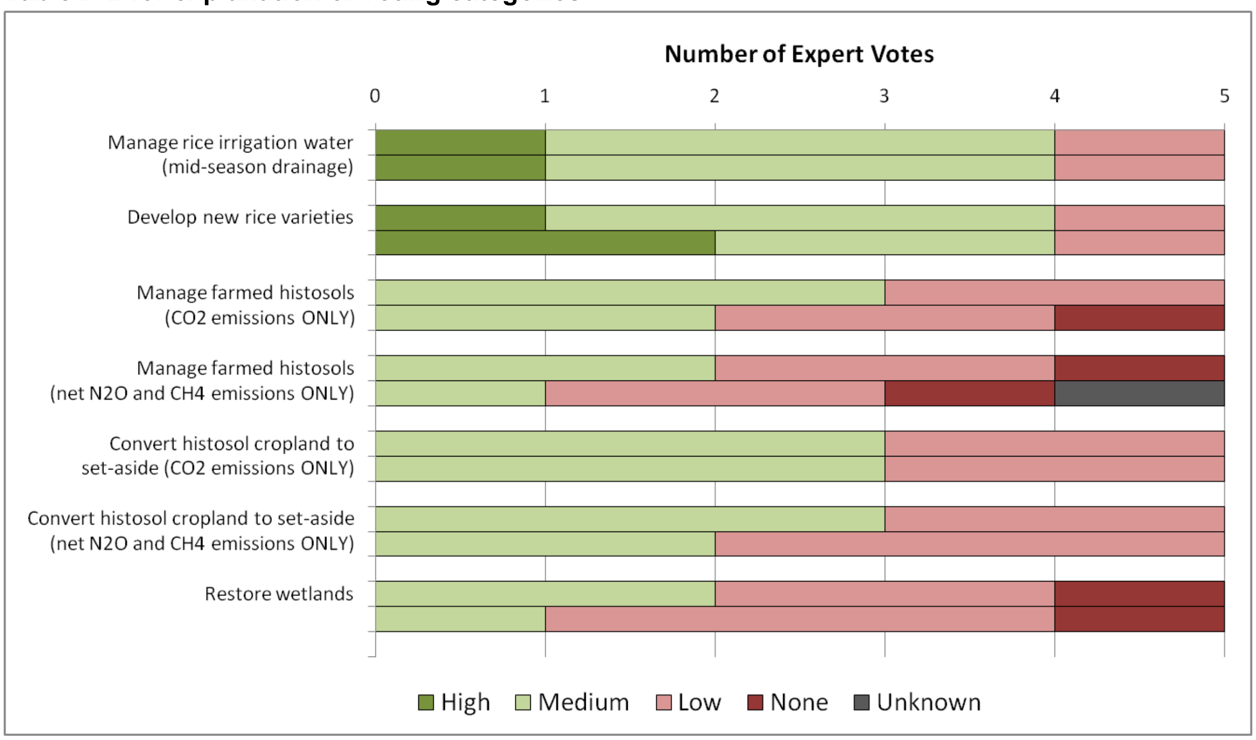

Figure B-4. Survey voting results for activities affecting CH_4 and multiple GHGs. The top bar for each activity represents the vote on confidence data, and the bottom bar, the vote on evidence. See Table B-2 for explanation of voting categories.