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Working Paper

Installment 6 of "Creating a Sustainable Food Future"

INDICATORS OF SUSTAINABLE AGRICULTURE: A SCOPING ANALYSIS

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SUMMARY

Quantifiable indicators of the environmental sustainability of agriculture—by which we mean minimizing the environmental impacts of agriculture—are an important tool for helping move the world toward a sustainable food future. Indicators enable policymakers, farmers, businesses, and civil society to better understand current conditions, identify trends, set targets, monitor progress, and compare performance among regions and countries.

What indicators are most appropriate for tracking progress and motivating actors toward a sustainable food future? To address this question, the World Resources Institute (WRI) conducted a scoping exercise to identify a preliminary list of candidate indicators at the nexus of agriculture and environment. This working paper describes the methods and results of this analysis.

First, we identified, analyzed, and profiled the landscape of existing indicators, indices, and datasets relevant to the environmental sustainability of agriculture.

Second, we selected the most relevant "thematic areas" for environmental sustainability in agriculture. These areas are water, climate change, land conversion, soil health, and pollution.

Third, we identified three generic stages of the "causal chain" of action that indicators can represent or seek to influence. These stages are public policy, farmer practice, and biophysical performance.

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Table 1a | **Short List of Candidate Indicators of Environmental Sustainability of Agriculture (Unit of measure)**

	WATER	CLIMATE CHANGE	LAND CONVERSION
Policy	Existence of policies requiring measurement of agricultural water withdrawals (Yes/No)[b]	Existence of policies promoting low greenhouse gas (GHG) agricultural development (Yes/No)[b]	Existence of policies limiting conversion of natural ecosystems to agriculture (Yes/No)[b]
Practice	Share of irrigated cropland area with efficient irrigation practices in place (percent)[a]	Share of farm area with agricultural GHG emissions management practices (percent)[b]	(1) Share of agricultural land enrolled in agricultural preserve programs (e.g., zoning to preserve production) (percent)[b] *and/or* (2) Share of former agricultural land in conservation set-aside program (percent)[b]
Performance	(1) Crop production per drop of water withdrawn (kilograms of crop produced per cubic meter of water per year) *in combination with* (2) Water stress ratio (water demand/ water supply in cubic meters)	Food production per unit of GHG emissions (tons of food produced per year per ton of CO_2 equivalent)[b]	(1) Conversion of natural ecosystems (e.g., forests, wetlands) to agricultural land (crop and pasture) (hectares of converted land per year)[a] *and/or* (2) Share of agricultural land over X years that was stable, share that shifted to natural land, and share that grew from natural land conversion (percent)[a]

Fourth, we selected seven screening criteria against which to assess candidate indicators. These screening criteria are availability of data, accuracy of data, consistency in how data are gathered, frequency of data, data's proximity to reality, relevancy of data, and ability for data to differentiate among countries.

Fifth, we identified a "long list" of candidate indicators of environmental sustainability in agriculture for each of the five thematic areas and for each of the three stages in the causal chain. Indicators came from our analysis of existing sources, as well as WRI expert input. We then evaluated each of these possible indicators against the seven screening criteria. Those that fared best became the "short list" of candidate indicators (Table 1).

Sixth, we explored options for how to integrate the indicators into an overall index on the environmental sustainability of agriculture.

We conclude by proposing a set of next-step activities for creating and establishing indicators of the environmental sustainability of agriculture. These include refining the selection of indicators, assessing the feasibility of successfully collecting currently missing data, and road testing the indicators. International organizations focusing on or investing in agriculture would be the natural implementers of these next steps.

INDICATORS AND A SUSTAINABLE FOOD FUTURE

The World Resources Report's *Creating a Sustainable Food Future: Interim Findings* describes how the world faces a great balancing act of three needs. It needs to close a 6,500 trillion kilocalorie per year gap between the food

Table 1b | **Short List of Candidate Indicators for Environmental Sustainability of Agriculture (Unit of measure)**

		POLLUTION	
	SOIL HEALTH	NUTRIENTS	PESTICIDES
Policy	Existence of policies that promote agricultural soil conservation practices (Yes/No)[b]	Existence of policies promoting nutrient management practices (Yes/No)[b]	Actions to ban or restrict pesticides and toxic chemicals under the Stockholm Convention (25-point scale)[a,c]
Practice	(1) Share of arable land under soil conservation practices (percent)[a] *and/or* (2) Share of cropland under conservation agriculture (e.g., organic soil cover greater than 30 percent immediately after planting) (percent)[a]	Share of agricultural land under nutrient management practices (percent)[a]	Share of cropland under integrated pest management (percent)[a]
Performance	(1) Share of agricultural land affected by soil erosion (percent)[a] *and/or* (2) Percent change in net primary productivity (NPP) across agricultural land (percent)[a] *and/or* (3) Soil organic matter (carbon) content (tons of carbon per hectare)[a]	(1) Nutrient input balances on agricultural land (i.e., difference between nitrogen [N] and phosphorus [P] inputs and outputs) (kilograms of N and P per hectare of agricultural land)[a] *and/or* (2) Fertilizer applied per unit of arable land (tons of nutrients per hectare of arable land)	Pesticide use per unit of cropland (tons of active ingredient applied per hectare)[a]

Notes:

a. Indicators that would require new effort to achieve more comprehensive and comparable data coverage and to establish regular data collection.

b. Indicators based on data that are currently unavailable, and would require new effort to design (e.g., develop a detailed definition and measurement protocol) and to establish regular data collection efforts.

c. The unit of measure for the pesticides policy indicator is a 25-point scale that measures the in-country status of 11 of the original chemicals listed in the Stockholm Convention on Persistent Organic Pollutants (POPs). A country is assigned three points for ratifying the treaty, two points for each POPs chemical banned, and one point for each POPs chemical restricted. The target score is 25.

available in 2006 and that required in 2050—a 69 percent increase—to adequately feed the planet. It needs agriculture to contribute to economic and social development. And it needs agriculture to reduce its impact on climate, water, and ecosystems.

The working paper series and interim findings of *Creating a Sustainable Food Future* explore a menu of solutions that combined could meet these three needs. Each working paper has explored promising approaches to establishing more sustainable food supply and demand (i.e., closing the food gap) while advancing economic development and reducing environmental impact (Box 1). This working paper explores indicators that could measure the impact of agriculture on various aspects of the environment. The proposed indicators would communicate to policymakers, farmers, the private sector, and civil society the degree to which agriculture is moving on a sustainable trajectory.

The proposed indicators measure what we call the "environmental sustainability of agriculture." Indicators for the economic and social dimensions of sustainable agriculture are beyond the scope of this working paper, but are clearly needed to comprehensively track progress toward a sustainable food future.

Box 1 | The World Resources Report: *Creating a Sustainable Food Future*

How can the world adequately feed more than 9 billion people by 2050 in a manner that advances economic development and reduces pressure on the environment? This is one of the paramount questions the world faces over the next four decades.

Answering it requires a "great balancing act" of three needs—each of which must be simultaneously met. First, the world needs to close the gap between the food available today and that needed by 2050. Second, the world needs agriculture to contribute to inclusive economic and social development. Third, the world needs to reduce agriculture's impact on the environment.

The forthcoming 2013–14 World Resources Report, *Creating a Sustainable Food Future*, seeks to answer this question by proposing a menu of solutions that can achieve the great balancing act. Some menu items address the demand for food, such as reducing food loss and waste and shifting diets. Other menu items address the supply of food, such as boosting yields through crop breeding, improving land and water management, and improving pasture productivity.

Since the 1980s, the World Resources Report has provided decisionmakers from government, business, and civil society with analyses and insights on major issues at the nexus of development and the environment. For more information about the World Resources Report and to access previous installments and editions, visit www.worldresourcesreport.org.

This working paper is grounded in analysis that WRI initially undertook to inform the design of a proposed Agricultural Transformation Index (ATI). The ATI would guide public and private sector decisionmaking by showing which countries are most conducive to being a farmer or conducting agribusiness and where policy initiatives are needed to promote inclusive and sustainable growth in the agricultural sector.[1] The ATI would cover conditions for agribusiness, policy-induced distortions, public investments, agricultural knowledge and technology systems, smallholder productivity, and environmental sustainability. WRI's task was to evaluate candidate indicators for the component on environmental sustainability in agriculture.

At the request of the donors supporting the ATI development process (including the government of Denmark), we set boundaries on the scoping exercise. First, it covered only land-based agriculture, and not wild fisheries or aquaculture. Second, it considered only the environmental dimension of sustainability and not the social or economic dimensions, since the latter may be captured in other indices.[2] Third, its geographic scope was national; the ATI would publish national indicators and indices that, among other applications, would compare performance among countries and stimulate a race to the top.

As this working paper went to press, the process for developing the ATI was still to be determined. Nonetheless, our research had yielded insights that could inform a standalone set of indicators, and even an index on the environmental sustainability of agriculture. In addition, it could contribute to other efforts exploring indicators on sustainable agriculture, such as the World Bank Group's "Benchmarking the Business of Agriculture" project, efforts by the World Bank and others to develop indicators on climate-smart agriculture, and multilateral efforts to establish post-2015 development goals.

This working paper summarizes the results of WRI's ATI scoping exercise. It begins by reporting the results of a review of existing indicators, indices, and datasets that address the environmental sustainability of agriculture. It then proposes five thematic areas that indicators should address and what screening criteria to use. The paper then presents a short list of candidate indicators that emerged when we applied the screening criteria against a long list of options. The paper concludes by proposing next steps for creating indicators of the environmental sustainability of agriculture.

INDICATORS OF THE ENVIRONMENTAL SUSTAINABILITY OF AGRICULTURE

Our first step in developing indicators of the environmental sustainability of agriculture was to review current indicators, indices, and datasets at the nexus of agriculture and the environment. What sources exist? What are their strengths and shortcomings? What can we learn from them?

To answer these questions, we identified, reviewed, and synthesized indicators, indices, and datasets related to the environmental sustainability of agriculture. Through discussions with experts at WRI and elsewhere, and an extensive literature review, we identified more than two dozen sources. We screened each for relevance and eliminated those deemed irrelevant. Table 2 summarizes the sources that passed the first screen.

We then profiled and summarized each source in "Landscape of Existing Agri-Environmental Indicators," an Excel workbook at http://www.wri.org/resources/data-sets/food-indicators. Each profile includes the source's lead developer or compiler, its objective, the most recent year and frequency of updates, its geographic coverage, and URL. For each indicator, we profiled its theme, metric, unit of measure, scale, and data source.

These profiles yielded several insights, including:

- No systematic global or near-global index of environmental sustainability of agriculture currently exists.
- The most relevant global index, Yale's *Environmental Performance Index*, includes agriculture as a small component of a much larger global assessment of national environmental performance within numerous economic sectors.
- The most thematically relevant report, the Organisation for Economic Co-operation and Development's (OECD's) *Environmental Performance of Agriculture in OECD Countries since 1990*, is geographically limited to 30 OECD member countries. It reports on each indicator separately and does not aggregate them into a single index. The OECD indicators can provide inspiration for the types of indicators to aspire to as data collection becomes better and more consistent globally.
- The most common themes of existing indicators are water use by agriculture, agriculture policies (especially agriculture subsidies), and greenhouse gas emissions from agriculture. Table 3 lists these and other common indicator themes and provides examples of specific indicators in each theme.
- No indicator perfectly reflects reality; each has limitations.
- On closer examination, many of the indicators used by the indices and reports profiled in "Landscape of Existing Agri-Environmental Indicators" turned out to be only tangentially related to measuring the environmental sustainability of increased food production.

Table 2a | **Sources Reviewed in Evaluating the Landscape of Environmental Indicators (not an exhaustive list)**

TYPE	TITLE	LEAD ORGANIZATION(S)
Index	Environmental Performance Index 2012	Yale Center for Environmental Law and Policy, Columbia University
Index	Environmental Vulnerability Index 2004	South Pacific Applied Geoscience Commission (SOPAC), United Nations Environment Programme (UNEP)
Index	Global Adaptation Index (GaIn) 2012	Global Adaptation Institute
Index	Hunger Reduction Commitment Index 2011	Institute of Development Studies
Index	Rice Bowl Index 2011	Frontier Strategy Group/Syngenta
Index	Rule of Law Index (2012– 2013)	World Justice Project
Report	Africa Capacity Indicators Report 2012	African Capacity Building Foundation
Report	Agricultural Policy: Monitoring and Evaluation (2012); Agricultural Policies in Emerging Economies: Monitoring and Evaluation (2009)	Organisation for Economic Co-operation and Development (OECD)
Report	Agricultural Science and Technology Indicators	International Food Policy Research Institute

Table 2b | **Sources Reviewed in Evaluating the Landscape of Environmental Indicators, continued (not an exhaustive list)**

TYPE	TITLE	LEAD ORGANIZATION(S)
Report	Environmental and Socioeconomic Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States 2012	Field to Market, The Keystone Alliance for Sustainable Agriculture, The Keystone Center
Report	Environmental Performance of Agriculture in OECD Countries since 1990	OECD
Report	Indicators from the Global and Sub-Global Millennium Ecosystem Assessments: An Analysis and Next Steps	World Resources Institute
Report	Integration of Environment into EU Agriculture Policy: The IRENA Indicator-Based Assessment Report 2006	European Environment Agency
Report	National Water Footprint Accounts: The Green, Blue, and Grey Water Footprint of Production and Consumption 2011	Water Footprint Network, UNESCO-IHE (International Institute for Hydraulic and Environmental Engineering) Institute for Water Education
Report	Resource Revolution: Meeting the World's Energy, Materials, Food, and Water Needs 2011	McKinsey Global Institute
Data	Aqueduct Water Risk Atlas	World Resources Institute
Data	Data Access Centre for Ozone Depleting Substances	UNEP Ozone Secretariat
Data	ECOLEX Global Database of Environmental Law	Food and Agriculture Organization of the United Nations (FAO), International Union for the Conservation of Nature (IUCN) and UNEP
Data	FAO AQUASTAT (Information system on water and agriculture)	FAO
Data	FAOSTAT (Information system on hunger, food, and agriculture)	FAO
Data	Global Eutrophic and Hypoxic Coastal Systems	World Resources Institute
Data	Soil property maps of Africa at 1 km resolution	Africa Soil Information Service (AfSIS), ISRIC-World Soil Information, World Agroforestry Centre (ICRAF)
Data	UNEP Environmental Data Explorer	UNEP
Data	UN Information Portal on Multilateral Environmental Agreements (InforMEA)	UNEP
Data	World Bank World Development Indicators—Agriculture and Rural Development	World Bank

Table 3 | **Most Common Themes among Indices, Reports, and Datasets Reviewed**

THEME	NUMBER OF OCCURRENCES	EXAMPLE OF INDICATOR
Water use	35	Total water use for agriculture production
Agricultural policy related to government support	18	Agricultural subsidies
Climate change	13	Greenhouse gas emissions from agricultural sources
Agricultural production	11	Crop yield
Agricultural inputs	10	Fertilizer use
Land use	10	Area of agricultural land
Environmental policy	10	Participation in UN Framework Convention on Climate Change (UNFCCC) treaties
Environmental degradation	7	Area of degraded/barren lands
Ecosystem biodiversity	6	Wild species in agricultural lands
Water quality	6	Number of dead (hypoxic) zones
Agricultural research and development	5	Public agricultural research expenditures
Ecosystem management	4	Area of terrestrial reserves
Agricultural policy related to the environment	4	Pesticide regulations

PARAMETERS FOR SELECTING CANDIDATE INDICATORS

To identify candidate indicators for the environmental sustainability of agriculture, we pursued a three-step process. First, we identified the most relevant "thematic areas" for indicators. These are the topics at the intersection of the environment and agriculture that we consider most significant—that is, where agriculture is a leading cause of environmental damage. Second, we identified the types of activity that indicators can seek to influence—what we call the "causal chain." Third, we selected a suite of screening criteria against which to assess candidate indicators. For each of these activities, we referred to existing indicators, indices, and datasets, as well as WRI expertise.

Thematic Areas

Agriculture impacts a variety of natural resources and environmental phenomena on a range of scales and with a host of consequences for human well-being. Based on our judgment of these impacts, we propose that any indicators of the environmental sustainability of agriculture cover at least five thematic areas. The first three are the focus of environmental concern in *Creating a Sustainable Food Future: Interim Findings*, namely:

- **WATER.** Agriculture accounts for 70 percent of the world's freshwater withdrawals[3] and for 80 to 90 percent of its freshwater consumption.[4]

- **CLIMATE CHANGE.** In 2010, about 13 percent of global anthropogenic greenhouse gas emissions came from agricultural production, most notably from ruminants, manure, fertilizers, rice, and on-farm energy use. Land use change, most of which is triggered by agriculture, contributed another 11 percent of global greenhouse gas emissions.[5]

- **LAND CONVERSION (TERRESTRIAL ECOSYSTEMS).** Since the dawn of the first agricultural revolution 8,000 to 10,000 years ago, growing crops and raising livestock have been the primary causes of loss and degradation of natural ecosystems.[6] Today, 37 percent of the planet's landmass outside of Antarctica is dedicated to growing food; 12 percent is in croplands and 25 percent is in grazing lands.[7] The majority of current land-use change in the world is forests, wetlands, and grasslands being converted into farms and grazing pastures. For instance, agriculture was responsible for roughly 80 percent of tropical deforestation between 2000 and 2010.[8] Land-use change can be a proxy for biodiversity loss, as well, since habitat loss is the world's most significant cause of biodiversity loss.[9]

Two other proposed thematic areas have cross-cutting importance for human well-being, food security, climate, water, and ecosystems, namely:

- **SOIL HEALTH.** Soil plays a key role in maintaining a balanced ecosystem and producing quality agricultural products.[10] However, soil erosion and degradation continue to threaten the availability and productivity of land for growing food. Annually, about 10 million hectares of cropland are abandoned because of soil erosion and related loss of productivity.[11] Soil is being lost 10 to 40 times faster than it is being replenished, which poses a threat to long-term human food security.[12] Furthermore, in many places, soil's capacity to retain nutrients, retain moisture, and maintain a healthy pH is declining.[13]

- **POLLUTION (NUTRIENTS, PESTICIDES).** Inputs of nutrients, particularly nitrogen and phosphorus, are essential for growing crops and supporting healthy crop yields. Maintaining balanced soil nutrient levels is critical to both production and environmental health: a deficiency in nutrients can reduce soil fertility and limit production, while surplus nutrients can lead to ecosystem degradation if they are lost to water or air. Impacts of excess nutrients on the environment include eutrophication of surface waters, impairment of groundwater, and emissions of harmful greenhouse gases, particularly nitrous oxide.[14] Agricultural nutrient pollution primarily stems from over-application or poorly timed application of fertilizers to cropland and waste from livestock. Furthermore, chemical pesticides—while beneficial for preventing crop losses to insects and other pests— and other chemicals can have detrimental effects on human health, wildlife, water quality, and other environmental factors depending on the toxicity of the constituent chemicals and the application conditions.

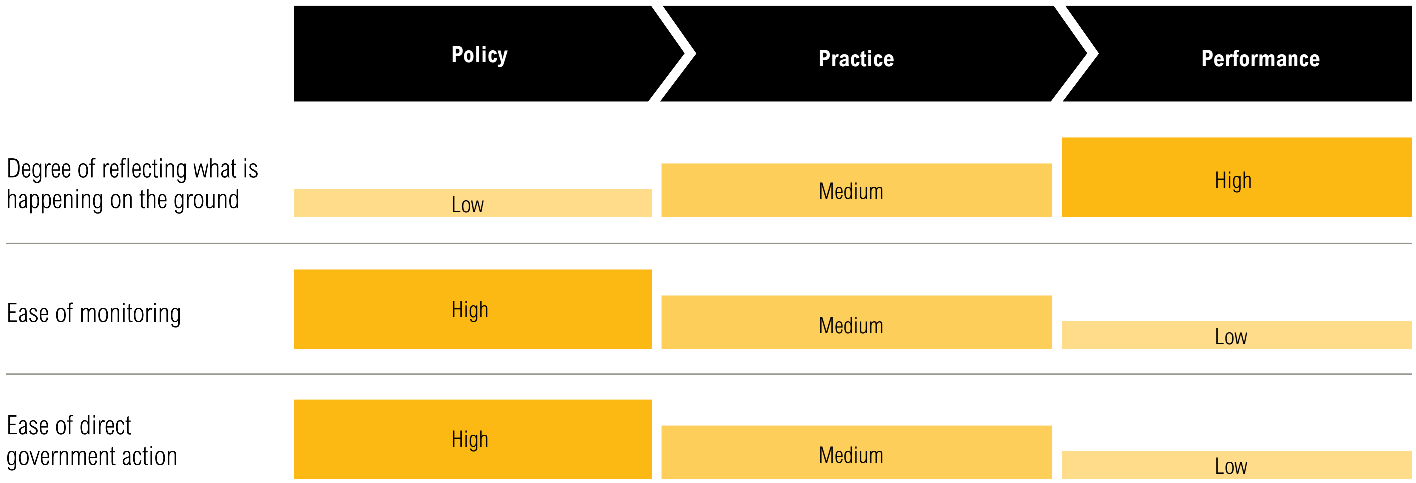
Stages in the Causal Chain

Indicators and indices seek to reflect and ultimately influence multiple types of behavior. For agriculture, they can reflect policies, practices, and performance—a sequence of behaviors and results or "causal chain." More specifically, government policies can influence farmer practices, which in turn can determine on-the-ground biophysical performance or conditions. For example, a regulation ("policy") that requires a farmer to measure the water she withdraws for crop irrigation can create an incentive for her to implement conservation irrigation techniques ("practice") which, in turn, can improve water-use efficiency and produce greater crop yield per unit of water used—or "crop per drop" ("performance").[15]

Ideally, a portfolio of indicators on the environmental sustainability of agriculture should reflect all three parts of the causal chain. Policy indicators reflect the policies that could create the right enabling conditions or incentives for sustainable agriculture. Practice indicators reflect the on-farm practices that help realize sustainable agriculture. Performance indicators reflect the desired, on-the-ground, biophysical state associated with sustainable agriculture.

Of course, the causal chain concept simplifies reality, which has complex interactions at political, social, and economic levels. For instance, a policy designed to prevent certain agricultural activities harmful to the environment may exist. But if it is not enforced, it may not affect farmer practices or on-the-ground performance. Nonetheless, this three-step structure can provide a useful framework for the types of indicators to select or develop.

Figure 1 | **Selecting Indicators of Sustainable Agriculture: Trade-offs across Steps in the Causal Chain**



Trade-offs in selecting indicators along this causal chain are illustrated in Figure 1. Although performance indicators are the best reflection of what is happening on the ground because they measure biophysical conditions, they are the hardest to mandate and to monitor. Policy indicators, conversely, reflect the existence of policies, some of which may be ineffective or unenforced, but they are arguably easier to monitor than biophysical conditions.

Screening Criteria

After identifying thematic areas and steps in the causal chain, we determined the criteria against which to assess the suitability of an environmental sustainability indicator. We used the following criteria:

- **AVAILABLE:** Are the data underlying the indicator currently available for most countries?
- **ACCURATE:** Are the data underlying the indicator accurate, reliable, and representative of on-the-ground conditions?
- **CONSISTENT:** Are the data collection methods consistent and the data comparable across all countries?
- **FREQUENT:** Are the data regularly collected or updated such that they are relatively current?
- **PROXIMATE:** Is the indicator or its data indicative of the environmental sustainability of agriculture with respect to the theme being considered? In other words, is it a good "proxy" for reality?
- **RELEVANT:** Is the indicator or its data highly pertinent to policy decisions involving environmental sustainability of agriculture?
- **DIFFERENTIATING:** Is the indicator or its data specific enough to show distinctions among countries?

To assess how well a candidate indicator meets one of these criteria, we developed a simple three-part scale of "high, medium, low" or "green, yellow, red," respectively. Table 4 summarizes the definitions of high, medium, and low for each of the screening criteria.

CANDIDATE ENVIRONMENTAL SUSTAINABILITY INDICATORS

Once the parameters were selected, we identified candidate indicators of environmental sustainability in agriculture. We began by generating a list of possible indicators for each of the five thematic areas and for each of the three steps in the causal chain. To generate this list, we used both indicators identified through our literature review and original indicators formulated by drawing on WRI

Table 4 | **Screening Criteria Scale Definitions**

CRITERION	HIGH 🟢	MEDIUM 🟡	LOW 🔴
Available	Data are currently available for most countries globally.	Data are currently available for some countries, but collection would be required for other countries.	Data are not currently available anywhere and would require new collection.
Accurate	Data are accurate, reliable, and representative of reality.	The accuracy, reliability, and/or representativeness of the data are unclear.	The existing data are inaccurate, unreliable, and/or unrepresentative of reality.
Consistent	Data collection methods are consistent across countries and the data are comparable across all countries.	Data collection methods may not be consistent and/or data may not be comparable across all countries.	Data collection methods are inconsistent and/or data are not comparable across countries (i.e., variation in time scales, baselines, definitions).
Frequent	Data are collected and/or updated on a regular basis and at a frequency such that the data are relatively current.	Data are collected and/or updated on an irregular basis, but might be more regularly updated in the future.	The data are currently not planned to be collected or updated again (i.e., they come from a one-time study).
Proximate	Data are indicative of the environmental sustainability of agriculture with respect to the theme being considered. They are a good "proxy."	Data are somewhat indicative of the environmental sustainability of agriculture with respect to the theme being considered, but they are not the ideal proxy.	Data are not indicative of the environmental sustainability of agriculture with respect to the theme being considered.
Relevant	Data are highly pertinent to policy decisions involving the environmental sustainability of agriculture.	Data could be relevant to policy decisions involving environmental sustainability of agriculture, depending on the context.	Data are too generic or too far removed from on-the-ground performance or practice and thus are not relevant to policy decisions.
Differentiating	Data are specific enough to show distinctions among countries.	Data could be elaborated to ensure that they are specific enough to show distinctions among countries.	Data are not specific enough to show distinctions among countries.

team expertise. We then evaluated each indicator against the seven screening criteria. Those that fared best became the initial "short list" of candidate indicators.

The Short-List Indicators and Metrics

"Evaluation of Candidate Indicators of Environmental Sustainability of Agriculture" (an Excel workbook available at http://www.wri.org/resources/data-sets/food-indicators) presents the list of possible indicators. Each worksheet is dedicated to a thematic area (e.g., water, climate, soil health) and is organized by step in the causal chain (i.e., policy, practice, performance) on one dimension and by selection criteria (e.g., available, accurate, consistent) on the other. Each possible indicator is evaluated against these criteria, accompanied by comments for clarification. The Excel workbook and Table 1 summarize the indicators selected to be on the short list.

Water

For the water theme, the candidate indicators are those that best reflect agricultural pressure on water resource use. Candidate indicators include:

- For policy, existence of policies requiring measurement of agricultural water withdrawals;
- For practice, share of irrigated cropland with efficient irrigation practices implemented; and
- For performance, agricultural water productivity (i.e., crop production per drop) combined with a water-stress ratio.

The water-stress ratio is used to distinguish between water-rich and water-poor countries. For example, a low crop-per-drop performance may not signal a problem in countries with low water stress (i.e., where water is abundant). Because water use is one of the most studied and documented aspects of agri-environmental sustainability, some data for this theme are available for most countries through sources such as the Food and Agriculture Organization of the United Nations (FAO). Nonetheless, we recommend improving existing datasets and gathering information at a more granular level.

Climate change

For the climate change theme, the candidate indicators are intended to capture the impact of agriculture on greenhouse gas (GHG) emissions and therefore on climate change. Candidate indicators include:

- For policy, the existence of policies promoting low-GHG agricultural development;
- For practice, the share of farms with GHG emissions management practices in place; and
- For performance, food production per unit of GHG emissions.

Given that GHG emissions are connected to many other agricultural activities covered in other themes, such as land-use conversion and soil erosion, capturing environmental sustainability in those themes could serve as a proxy for climate change. Thus the indicators presented here measure specific activities related to emissions and can reinforce the indicators in other themes.

Land conversion

This theme is intended to capture indicators of natural land being converted to agriculture, which in turn can have implications for biodiversity, climate change, and other environmental issues. The candidate indicators for the land-conversion theme include:

- For policy, existence of policies limiting conversion of natural ecosystems to agriculture;
- For practice, share of agricultural land enrolled in agricultural preserve programs (e.g., zoning to preserve production) and/or share of former agricultural land in conservation set-aside programs; and
- For performance, area of and/or share of natural land converted to or from agriculture.

Soil health

This theme covers indicators of the impact of agriculture on soil health and productivity, including:

- For policy, the existence of policies promoting agricultural soil conservation practices;
- For practice, share of farmland under soil conservation practices and/or share of cropland under conservation agriculture; and
- For performance, area of agricultural land affected by soil erosion, and/or percent change in net primary productivity (NPP) across agricultural land, and/or soil organic matter (carbon) content.

Nutrients

This theme represents indicators of environmental degradation caused by agricultural nutrient inputs, including:

- For policy, the existence of policies or incentives to promote nutrient management practices;
- For practice, the share of agricultural land under nutrient management practices; and
- For performance, nutrient input balances (i.e., ratio of inputs to outputs) and/or fertilizer applied per unit of arable land.

Pesticides

This theme covers indicators of the environmental impact of agricultural pesticides and other pollutants, including:

- For policy, the degree to which the country has regulated pesticides and other chemicals that pose significant risks to health and the environment, according to the Stockholm Convention;

- For practice, the share of cropland under integrated pest management; and
- For performance, the extent of pesticide use per unit of cropland.

Some Caveats

A few caveats are important. First, given that this working paper summarizes a scoping exercise, the candidate list represents those indicators that we deem most suitable for further research and vetting—particularly with regard to data availability, accuracy, and frequency of collection. Second, we did not restrict selection of candidate indicators to those for which data are already available in all countries. Although some suggested candidate indicators may fare poorly on the data availability criterion, they would be accurate, proximate, relevant, and differentiating. We include them as a signal that the international community should consider generating and collecting data for these indicators. Table 5 summarizes our data assessment and highlights which indicators would require new design and data collection efforts.

Table 5a | **Candidate Indicators: Summary of Data Assessment**

● = high ● = medium ● = low ● = N/A

		INDICATOR (UNIT OF MEASURE)	ARE THE DATA... CURRENTLY AVAILABLE?	ACCURATE?	CONSISTENT ACROSS COUNTRIES?	REGULARLY COLLECTED?	GOOD PROXY FOR ENV. SUSTAINABILITY?	RELEVANT TO DECISIONMAKING?	DIFFERENTIATING?	COMMENTS
WATER	POLICY	Existence of policies requiring measurement of agricultural water withdrawals (Yes/No)[b]	low	N/A	N/A	N/A	high	high	high	Assuming that water that is measured is more likely to be managed, this indicator serves as a proxy for withdrawal management.
	PRACTICE	Share of irrigated cropland area with efficient irrigation practices in place (percent)[a]	medium	medium	medium	low	high	high	high	Indicates level of effort to conserve water resources through water-efficient irrigation (covers irrigated agriculture). Existing data are sourced from a one-time study and not updated regularly.
	PERFORMANCE	Crop production per drop of water withdrawn (kilograms of crop produced per cubic meter of water per year)	high	medium	medium	medium	high	high	high	Incorporating productivity with agricultural water withdrawals provides an indicator of efficiency in the country's agricultural water use. Water consumption (e.g., the actual water consumed by crops) would be a better indicator, but in the absence of such information, water withdrawal is a good proxy.
		Water-stress ratio (water demand/water supply in cubic meters)	medium	high	high	low	medium	high	high	This indicator would be used with the other water use indicators to distinguish between water-rich and water-poor countries, thereby setting a context for agricultural water use. Existing data are sourced from a one-time study and not updated regularly.

Table 5b | **Candidate Indicators: Summary of Data Assessment, continued**

● = high ● = medium ● = low ● = N/A

		INDICATOR (UNIT OF MEASURE)	ARE THE DATA... CURRENTLY AVAILABLE?	ACCURATE?	CONSISTENT ACROSS COUNTRIES?	REGULARLY COLLECTED?	GOOD PROXY FOR ENV. SUSTAINABILITY?	RELEVANT TO DECISIONMAKING?	DIFFERENTIATING?	COMMENTS
CLIMATE CHANGE	POLICY	Existence of policies promoting low greenhouse gas (GHG) agricultural development (Yes/No)[b]	low	N/A	N/A	N/A	high	high	high	National adoption of low-GHG development policies for agriculture indicates government prioritization of climate-friendly growth of the agricultural sector.
CLIMATE CHANGE	PRACTICE	Share of farm area with agricultural GHG emissions management practices (percent)[b]	low	N/A	N/A	N/A	high	high	high	Indicator provides insight into the degree of adoption of GHG mitigation practices.
CLIMATE CHANGE	PERFORMANCE	Food production per unit of GHG emissions (tons of food produced per year per ton of CO_2 equivalent)[a]	medium	medium	medium	high	high	high	high	Ideally, these emissions data would be based on national aggregation of farm-level GHG inventories and on measurement approaches that offer greater accuracy than the default International Panel on Climate Change (IPCC) Tier 1 approaches that measure on a national level. However, this would require considerable resource investment. In lieu of this, national data would suffice.
LAND CONVERSION	POLICY	Existence of policies limiting conversion of natural ecosystems to agriculture (Yes/No)[b]	low	N/A	N/A	N/A	high	high	high	Indicates political will and government commitment to managing land use. This indicator would require defining what constitutes appropriate policies for limiting land conversion.
LAND CONVERSION	PRACTICE	Share of agriculture land enrolled in agricultural preserve programs (e.g., zoning to preserve production) (percent)[b]	low	N/A	N/A	N/A	high	high	high	In some countries, local governments have established zoning measures to preserve agricultural production areas close to urban areas or have created incentives to encourage transition of agricultural land back into natural ecosystems.
LAND CONVERSION	PRACTICE	Share of former agricultural land in conservation set-aside program (percent)[b]	low	N/A	N/A	N/A	high	high	high	

Table 5c | **Candidate Indicators: Summary of Data Assessment, continued**

● = high ● = medium ● = low ● = N/A

		INDICATOR (UNIT OF MEASURE)	ARE THE DATA… CURRENTLY AVAILABLE?	ACCURATE?	CONSISTENT ACROSS COUNTRIES?	REGULARLY COLLECTED?	GOOD PROXY FOR ENV. SUSTAINABILITY?	RELEVANT TO DECISIONMAKING?	DIFFERENTIATING?	COMMENTS
LAND CONVERSION	PERFORMANCE	Conversion of natural ecosystems (e.g., forests, wetlands) to agricultural land (crop and pasture) (hectares of converted land per year)[a]	medium	medium	medium	medium	high	high	high	Measures the annual net change in agricultural land per country, as well as information on type of land being converted. The absolute value (hectares of converted land) measures contribution to global change. The second relative value (share of agricultural land) measures progress in stabilizing the land area used for cropping and grazing. Investment in satellite remote-sensing data collection and processing would provide increased coverage and consistency across countries.
LAND CONVERSION	PERFORMANCE	Share of agricultural land over X years that was stable, share that shifted to natural land, and share that grew from conversion of natural land (percent)[a]	medium	medium	medium	medium	high	high	high	
SOIL HEALTH	POLICY	Existence of policies that promote soil conservation practices (Yes/No)[b]	low	N/A	N/A	N/A	high	high	high	Policies could include those encouraging reduced tillage, windbreaks, agroforestry, and more.
SOIL HEALTH	PRACTICE	Share of arable land under soil conservation practices (percent)[a]	medium	high	high	low	high	high	high	These data capture the variety of soil management practices, but are limited in geographic coverage.
SOIL HEALTH	PRACTICE	Share of cropland under conservation agriculture (e.g., organic soil cover greater than 30 percent immediately after planting) (percent)[a]	medium	medium	medium	medium	medium	medium	high	These data are currently available, but the organic soil cover metric is not as meaningful as a metric that would indicate the presence of low-till or no-till technology.
SOIL HEALTH	PERFORMANCE	Share of agricultural land affected by soil erosion (percent)[a]	medium	medium	medium	medium	high	high	high	Soil erosion is a key indicator of land degradation and loss of agricultural productivity. It also can indicate impacts on water quality and aquatic ecosystem health.

Table 5d | **Candidate Indicators: Summary of Data Assessment, continued**

● = high ● = medium ● = low ● = N/A

		INDICATOR (UNIT OF MEASURE)	ARE THE DATA... CURRENTLY AVAILABLE?	ACCURATE?	CONSISTENT ACROSS COUNTRIES?	REGULARLY COLLECTED?	GOOD PROXY FOR ENV. SUSTAINABILITY?	RELEVANT TO DECISIONMAKING?	DIFFERENTIATING?	COMMENTS
SOIL HEALTH	PERFORMANCE	Percent change in net primary productivity (NPP) across agricultural land (percent)[a]	medium	medium	medium	medium	high	high	high	Existing data and estimates of net change in NPP for the period 1981 to 2006 could be used, but a better indicator would involve annual estimates of Normalized Difference Vegetation Index (NDVI) change to better capture proxies for current soil degradation upon normalizing for climate, soil type, land use, and other factors.
SOIL HEALTH	PERFORMANCE	Soil organic matter (carbon) content (tons of carbon per hectare)[a]	medium	high	high	medium	high	high	high	Soil organic carbon is a critical component of soil that indicates soil health and productivity.
NUTRIENTS	POLICY	Existence of policies promoting nutrient management practices (Yes/No)[b]	low	N/A	N/A	N/A	high	high	high	The existence of incentives or regulations for nutrient management is general enough to indicate environmentally sustainable policies whether the prevailing objective is to prevent nutrient runoff or improve soil fertility, as dictated by national conditions and/or level of socioeconomic development.
NUTRIENTS	PRACTICE	Share of agricultural land under nutrient manage-ment practices (percent)[a]	medium	medium	low	medium	high	high	high	Indicates the extent of nutrient management adoption, but data are currently limited in geographic coverage. Data are based on country-specific research and thus some countries may have different criteria for defining this indicator.
NUTRIENTS	PERFORMANCE	Nutrient input balances on agricultural land (i.e., difference between nitro-gen [N] and phosphorus [P] inputs and outputs) (kilograms of N and P per hectare of agricul-tural land)[a]	medium	medium	high	medium	high	high	high	This indicator captures the nutrient requirements of crops in addition to fertilizer consumption, normalized by scale of agricultural area.

Table 5e | Candidate Indicators: Summary of Data Assessment, continued

● = high ● = medium ● = low ● = N/A

		INDICATOR (UNIT OF MEASURE)	ARE THE DATA... CURRENTLY AVAILABLE?	ACCURATE?	CONSISTENT ACROSS COUNTRIES?	REGULARLY COLLECTED?	GOOD PROXY FOR ENV. SUSTAINABILITY?	RELEVANT TO DECISIONMAKING?	DIFFERENTIATING?	COMMENTS
NUTRIENTS	PERFORMANCE	Fertilizer applied per unit of arable land (tons of nutrients per hectare of arable land)	medium	medium	medium	medium	high	high	high	Lower fertilizer consumption per unit of arable land does not necessarily indicate better environmental sustainability. Countries and regions vary regarding the levels of nutrients naturally found in their soils and thus the added amount needed to support agricultural yields. Likewise, farms vary in terms of their nutrient utilization potential.
PESTICIDES	POLICY	Actions to ban or restrict pesticides and toxic chemicals under the Stockholm Convention (25-point scale)[a,c]	medium	medium	medium	medium	medium	medium	medium	Measures some national actions to ban or restrict pesticides and other chemicals that threaten ecosystems and human health. Data are infrequent and difficult to verify. Relying on the original Stockholm Convention chemicals alone offers little discrimination among most countries.
PESTICIDES	PRACTICE	Share of cropland under integrated pest management (percent)	medium	medium	low	medium	high	medium	high	Global data would be difficult to collect, given that the OECD can only obtain these data for 12 countries. Data are based on country-specific research and thus some countries may have different criteria for defining this indicator.
PESTICIDES	PERFORMANCE	Pesticide use per unit of cropland (tons of active ingredient applied per hectare)	high	medium	medium	high	medium	medium	high	Indicates level of pesticide use per country normalized by area of cropland (though the definition of "use" may vary among countries and crops). "Tons of active ingredient applied per hectare" does not provide sufficient differentiation between pesticides. Some are more toxic or harmful to the environment on a per ton basis than others.

Notes:

a. Indicators that would require new effort to achieve more comprehensive and comparable data coverage and to establish regular data collection.

b. Indicators based on data that are currently unavailable, and would require new effort to design (e.g., develop a detailed definition and measurement protocol) and to establish regular data collection efforts.

c. The unit of measure for the pesticides policy indicator is a 25-point scale that measures the in-country status of 11 of the original chemicals listed in the Stockholm Convention on Persistent Organic Pollutants (POPs). A country is assigned three points for ratifying the treaty, two points for each POPs chemical banned, and one point for each POPs chemical restricted. The target score is 25.

Third, in the Excel workbook, we offer ideas for how to collect missing data. For instance, remote sensing—which can detect soil degradation or land conversion to agriculture—is quickly advancing in terms of resolution, coverage, and processing costs, and could increase in importance as a data source on the environmental performance of agriculture. Furthermore, many environmental policy indicators simply have not yet been compiled at a multinational level. In short, we recommend some indicators with an eye toward their future potential.

Fourth, the candidate list does not include demand-side aspects such as measuring rates of post-harvest food loss and waste. This is outside the scope of the analysis.

Integrating the Indicators into an Index

Some stakeholders may want individual indicators that can stand on their own. Others might want to integrate the indicators into a single index in order to compare countries.[16] Integration involves weighting and aggregating the constituent indicators of the index. The constituents are assigned weights based on statistical criteria or expert judgment. Then they are aggregated in either a linear or nonlinear fashion.[17] Options for weighting and aggregating indicators for an index are described below and shown in Figure 2.

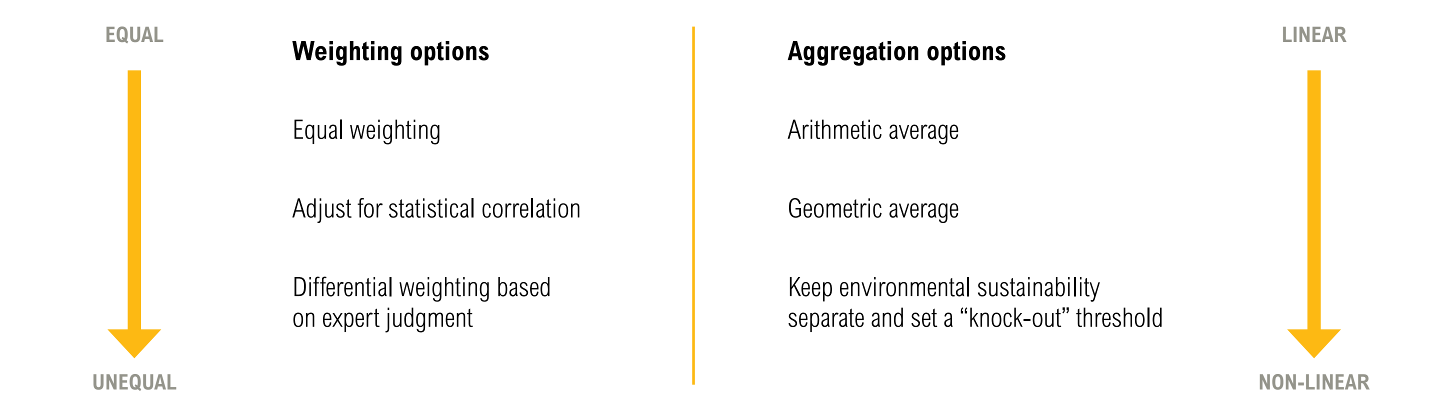
Weighting

- **EQUAL WEIGHTING:** This approach gives all components equal significance in the index.
- **ADJUSTED WEIGHTS BASED ON STATISTICAL CORRELATION:** This approach uses a correlation coefficient to test components to either (1) choose only components that have a low degree of correlation and assign equal weights, or (2) adjust the weights of components according to their degree of correlation (e.g., give less weight to correlated indicators). This approach avoids double counting or biasing the index in favor of statistically similar components.
- **DIFFERENTIAL WEIGHTING BASED ON EXPERT JUDGMENT:** This approach involves convening a group of experts to assign weights to components based on their judgment of which components are more or less important in reflecting policy priorities or other objectives of the index.

Aggregating

- **ARITHMETIC AVERAGE:** This linear approach sums all components and divides them according to the size of the collection. This approach values each component in equal proportion. The result is that a high score for one component can compensate for a proportionally lower score for another component.

Figure 2 | **Approaches for Integrating Indicators**



Note: Literature review would be necessary to determine degree of correlation between indicators and to make any appropriate statistical corrections.

- **GEOMETRIC AVERAGE:** This nonlinear approach uses the product of the components to the n^{th} root (where n is the size of the collection).This approach rewards a component's high score and penalizes a low score more than a linear aggregation approach. Thus it is much more difficult for a high score in one component to offset or compensate for a low score in another component.
- **ASSIGNING A "KNOCK-OUT" THRESHOLD:** In this approach, a minimum threshold value is set that components must meet to be included in the aggregation. Failure of one component to meet its threshold prevents the aggregation from occurring. This approach could also apply to the integration of the environmental sustainability index into a larger agricultural index. For example, if a country fails to meet a minimum threshold for environmental sustainability, it would not receive an overall index "score" or would receive a very poor score, no matter how well the country performs on the other indices.

When integrating indicators into an overall index, it is important to keep five points in mind. First, no single integration approach for designing an index is considered statistically or scientifically superior to another: all represent value judgments.[18] Second, the approach selected depends largely on the index's intended purpose.[19] Third, avoid using constituent indicators that overlap or cover the same issue; they will "double count" in the aggregate index. Fourth, avoid constituent indicators that are the opposite of each other; they will zero each other out in the aggregate index. Fifth, recognize that an aggregate index may be too broad for some audiences to derive a clear message regarding the meaning and implications of the index. Too much information may be integrated, making the result unclear or even misleading. Therefore, stakeholders considering combining indicators into one index should proceed with caution.

PROPOSED NEXT STEPS

Designing indicators or an index for the environmental sustainability of agriculture will require new work. It is not possible to simply adopt or repackage existing materials into a sufficiently robust index or set of indicators. Although data exist for some indicators, information gaps hinder designing a suite of indicators and an associated index that sufficiently covers the range of important thematic areas. Closing these gaps will require a collaboration of partners with a variety of expertise, ranging from data gatherers and statisticians to agriculture and sustainability experts.

Given the wide variation in data availability, a pragmatic process for developing the indicators and an index could be to first produce a version 1.0 that is later replaced by a version 2.0. Version 1.0 would be based on indicators for which data are readily available, including existing global datasets from FAO and the World Bank. Version 1.0 could serve as a "first cut" set of indicators and index. Version 2.0 would build on version 1.0 over time by adding or substituting novel indicators that require substantial, new data collection.

The following section provides an overview of the activities and end products that could lead to a useful suite of indicators (or even an index) on the environmental sustainability of agriculture.

Activities

To advance development of the indicators:

- Refine the purpose, scope, and target audience of environmental sustainability of agriculture indicators.
- Confirm or refine the parameters for selecting candidate indicators (e.g., thematic areas, causal chain, screening criteria) identified in this scoping exercise.
- Applying these parameters, refine the selection of optimal candidate indicators, identifying those that could be prepared relatively quickly for a version 1.0, and those that may be ideal but will require time to develop or collect the requisite data and thus could be part of a version 2.0. Assess whether there are "threshold effects" that candidate indicators need to reflect for a particular thematic area.
- For the candidate indicators to be included in version 2.0, contact and engage existing and prospective providers of the requisite data. Develop a "data gathering" (for existing data) and "data generation" (for missing data) strategy, create a "mandate" or demand signal for missing requisite data to be collected, and develop a financing plan for funding the generation and/or collection of that data.

To test the indicators and create an index (for versions 1.0 and 2.0):

- Road test the candidate indicators and data collection in at least a dozen countries representing different degrees of agricultural development, to determine feasibility of gathering sufficient data and to refine indicator designs.
- Start collecting data for a full set of countries based on insights from the road tests.

- Refine the weighting and aggregation method for combining indicators into an index. Engage statisticians and other experts on creating composite indices to evaluate and refine the methodology for combining indicators. Where necessary, conduct multivariate analysis to determine the suitability of the underlying datasets, adjust datasets to account for outliers, and perform sensitivity analysis of the index.
- If one opts to merge the indicators into an index, conduct validation tests on the index to determine correlation and to explore causality among outcome variables of interest and a set of explanatory indicators. Validation tests could use regression analysis, principle component analysis, factor analysis, or hypothesis testing.
- Produce the environmental sustainability of agriculture indicators (and index).

To publish and promote the results:

- Develop and publish a report summarizing the rationale, methods, content, and results of the environmental sustainability indicators (and index).
- Develop (or provide content to) an online platform that displays the results of the environmental sustainability of agriculture indicators, index (if chosen), and the underlying data. Transparency in the design of the indicators, index, and the constituent data is paramount to its uptake and credibility. Providing open access to the raw and calibrated data will drive further study and evaluation of environmental sustainability.
- Conduct outreach regarding the indicators (and index) to raise awareness of their existence and utility and to stimulate use.
- Develop a long-term funding and maintenance strategy for the indicators (and index).

End Products

The end products of this effort might include:

- An operational set of "environmental sustainability of agriculture" indicators (and index).
- Published reports on these indicators (and index), including their purpose ("why"), details on their component data ("what"), and description of how they are designed and compiled ("how").
- Infographics to clearly and simply convey the results and main messages of the indicators (and index).
- A website for showcasing indicator (and index) results, interpretation, and access to component datasets.

Whom to Engage

Entities to engage in this process include those that could provide data for indicators, those that could track the indicators, and those whose actions might be influenced by the indicators. These entities include (but are not limited to) the FAO, the OECD, the CGIAR[20] research centers, national agriculture ministries (for feedback on indicators and their application), national environment ministries, the World Bank, bilateral development agencies, and research organizations. One institution should become the "lead" for developing the indicators (and index).

Concluding Thoughts

Quantifiable indicators of the environmental sustainability of agriculture will enable policymakers, farmers, businesses, and civil society to better understand current conditions, identify trends, set targets, monitor progress, and compare performance among regions and countries. If appropriately designed, they can foster incentives for the sector or nations to improve performance. And they make managing the nexus between agriculture and the environment easier; it is hard to manage that which is not measured. For these reasons, indicators are an important ingredient in achieving a sustainable food future.

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ENDNOTES

1. DANIDA (2013).
2. Such as the Better Business in Agriculture index being developed by the World Bank and the International Finance Corporation.
3. FAO (2013).
4. Foley et al. (2005).
5. Searchinger et al. (2013). Climate change, in turn, can impact agricultural productivity and thus agriculture will need to adapt to climate change over time to maintain yields. But climate change adaptation is better suited to be part of a suite of agriculture productivity indicators, since adapting to climate change is not about reducing agriculture's impact on climate but rather about enabling agriculture to maintain yields as the climate changes.
6. Millennium Ecosystem Assessment (2005).
7. Figures exclude Antarctica. FAO (2011).
8. Kissinger et al. (2012).
9. Millennium Ecosystem Assessment (2005).
10. OECD (2003).
11. Faeth and Crosson (1994).
12. Pimentel (2006).
13. Personal communication, Mike McGahuey (USAID), April 4, 2013.
14. OECD (2008).
15. This framing somewhat mimics the "driver-pressure-state-impact-response" framework. See ia2dec.ew.eea.europa.eu/knowledge_base/Frameworks/doc101182.
16. Some stakeholders may want to generate a single index in order to raise attention about the relative environmental sustainability of agriculture among nations, but then encourage audiences to explore the constituent indicators to understand performance at a more granular level.
17. Nardo et al. (2005).
18. Nardo et al. (2005).
19. Nardo et al. (2005).
20. CGIAR = Consultative Group on International Agricultural Research

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