



**Science
Societies**

Environmental outcomes from on-farm agricultural production in the United States

**Part 1: Land use, soil erosion, irrigation water use,
energy use, and greenhouse gas emissions**

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In flooded rice, biological nutrient cycling releases methane, a greenhouse gas. Photo courtesy of Flickr/formulanone.

This article is brought to you by the SPARC Initiative created in partnership among the American Society for Agronomy, the Agricultural Retailers Association, Environmental Defense Fund, and Field to Market: The Alliance for Sustainable Agriculture to empower trusted advisers to deliver services that drive continuous improvement in the productivity, profitability, and environmental outcomes of farmers' operations. Learn more about the

SPARC Initiative and access additional resources, including the six-module series on sustainability at www.fieldtomarket.org/SPARC. This article is an excerpt from Field to Market's Fourth *National Indicators Report*, released in December 2021. Access the entire report at www.fieldtomarket.org/report. Sections covering soil carbon, biodiversity, and water quality will be included in future issues of *Crops & Soils* magazine.

Sustainability Programming for Ag Retailers and CCAs (SPARC)



U.S. croplands are some of the most productive agricultural areas on the planet and provide food, feed, fiber, and fuel for domestic consumption and export. As a critical region for global food security, maintaining the productivity of U.S. cropland is key to achieving the United Nations' Sustainable Development Goal (SDG) of "Zero Hunger" by ensuring adequate, nutritious food for a growing population (United Nations, 2015). At the same time, the harmful environmental impacts from the past centuries of farming on these lands have been considerable and at odds with other SDGs including Clean Water, Life on Land, Life Below Water, and Climate Action. Recent progress reports on

the SDGs highlighted the important role of agricultural value chain stakeholders and partnerships in devising solutions to achieve Zero Hunger (Veldhuizen et al., 2020) as well as the need to focus on the interconnections between the goals and to strive for achieving synergistic improvements (Messerli et al., 2019). Balancing these goals is the critical challenge facing agricultural producers and stakeholders over the coming decade.

Since 2009, Field to Market has tracked progress towards improvement in five key environmental indicators through three editions of the *National Indicators Report* (Field to Market, 2009, 2012, 2016). The fourth edition of the report extends the analysis from 1980 to 2020 to examine how trends in five key environmental indicators—land use, energy use, greenhouse gas emissions, irrigation water use, and soil erosion—have evolved over the past four decades.

Recent results from surveys and the 2017 USDA Census of Agriculture demonstrate continued adoption of conservation practices that are key to sustainable systems. However, long-term data indicate that conversion to reduced- and no-tillage systems has slowed in recent years, only expanding from 104 million acres to 112 million acres between 2012 and 2017 (USDA-NASS, 2019). Increase in cover crop acreage has been more significant over that time period; however, the total extent of cover crop adoption remains relatively low at 5.1% of harvested cropland for all crops in 2017 (Wallander et al., 2021). An assessment by the USDA Economic Research Service documented the success of private- and public-sector financial incentives for increasing conservation practice adoption, indicating significant room for further adoption through expansion of such programs (Wallander et al., 2021). It is incumbent on the agricultural industry and stakeholders to identify and eliminate barriers to adoption and make conservation practices the best choice for farmers throughout the

country.

While this engagement, and that of other organizations with sustainable agriculture goals is promising, we can't determine progress at a national scale by focusing only on individual efforts and case studies. To understand whether these efforts are having a broader impact discernable throughout the agricultural system requires examining national trends using statistically robust data sets. The fourth edition of the *National Indicators Report* provides a progress report and reality check to help ground and direct future efforts. The overall objective of this report is to assess trends in eight key environmental indicators from 1980 to 2020. For five of the indicators—land use, irrigation water use, energy use, greenhouse gas emissions, and soil erosion—we use government statistics and scientific literature to calculate crop-specific trends for the full time period.

Environmental Indicators

The five environmental indicators discussed here assess the efficiency of crop production at the national scale from 1980–2020 for 11 major crops. Indicator calculations are described briefly below and more fully in Appendix A of the full report (Field to Market, [2021](#)).

Land Use

The land use indicator measures the production efficiency of agricultural lands and is closely tied to crop yields, which are key to economically sustainable farming operations. Optimal yields are critical to economic sustainability and other efficiency indicators.

Soil Erosion

Sustainable agriculture strives to improve soil conservation by reducing erosion to preserve healthy soils for future productivity and land resiliency. Soils are highly variable throughout the country, having been formed over millennia by natural geologic and climatic processes and impacted by land use history and management. Soil erosion occurs when the soil surface is exposed to water and wind. While soil continues to form, the rate is much slower than losses due to erosion in and near farm fields. The soil erosion indicator included in this report is a high-level assessment of the rate of soil loss from cultivated lands and is expressed as the amount of soil lost via wind and water per acre. Reductions in loss of soil per acre are key to sustaining productivity, regardless of crop yield values.

Irrigation Water Use

Water is an important limiting factor for crop production where precipitation is not sufficient or does not occur at the right time for optimum crop yields. Irrigation is increasingly limited by available surface and groundwater and is susceptible to shortages due to droughts. Agriculture is the single largest consumptive water user in the United States (Moore et al., 2015) and is thus the sector most vulnerable to changes in weather and climate (Marshall et al., 2015) and to depletion of groundwater resources (Konikow, 2014). As drought continues to expand and intensify across the western U.S., improvements in irrigation water use efficiency are critical to maintaining production without depleting aquifers and surface water storage reserves for other uses in water-stressed regions. The Irrigation Water Use indicator assesses the efficiency of irrigation water applied in terms of the incremental improvement it produces in crop yield compared with yields on non-irrigated lands and is applicable only to irrigated lands.

Energy Use

From pumping irrigation water, to manufacturing nitrogen fertilizer, to powering farm equipment, agriculture uses energy in many forms. This indicator assesses trends in energy use efficiency of crop production in the U.S. by evaluating the amount of energy used relative to crop yield. Energy use is also an important indicator for evaluating the cost of production of a farm operation.

Greenhouse Gas Emissions

Greenhouse gas (carbon dioxide, nitrous oxide, and methane) emissions from crop production come from three main sources. One is the emissions associated with energy use, which depend on both the amount of energy and the form (diesel, electricity, etc.) of that energy. Another is direct emissions from biological nutrient cycling in agricultural soils, which release nitrous oxide and, for flooded rice, methane. The third source is the emissions resulting from burning crop residues to clear fields after harvest. By examining the trends in these sources, we can identify opportunities for emissions reductions that contribute to climate mitigation.

Crop-Specific Trends

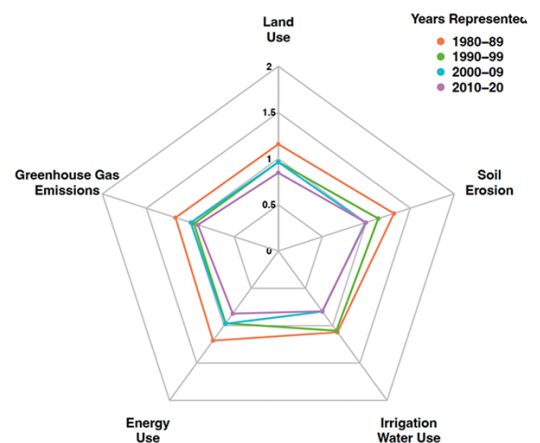
Overall, the five indicators, when calculated at a national scale, provide a broad view of the changes over time in the environmental impact of crop production. The calculations are designed to capture trends on a crop-specific basis. Summaries for each of the 11 crops are found in Table 1 and below.

Table 1. Crops included and unit of production for analysis

Crop	Yield unit	Description
Barley	bu	Bushel, 48 lb grain/bu (14.5% moisture)
Corn (grain)	bu	Bushel, 56 lb grain/bu (15.5% moisture)
Corn (silage)	ton	2,000 lb (65% moisture)

Crop	Yield unit	Description
Cotton	lb of lint	Pounds (lb) of lint (5% moisture)
Peanuts	lb	Pounds (lb) (10.5% moisture)
Potatoes	cwt	Hundredweight, 100 lb (fresh harvest)
Rice	cwt	Hundredweight, 100 lb (13% moisture)
Sorghum	bu	Bushel, 56 lb grain/bu (12.5% moisture)
Soybeans	bu	Bushel, 60 lb seed/bu (13% moisture)
Sugarbeets	ton of sugar	2,000 lb (fresh harvest)
Wheat	bu	Bushel, 60 lb grain/bu (13.5% moisture)

Barley



Sample summary chart for barley: Data are presented in index form where all indicators have been scaled by indicators averages for the period 1998–2002. A 0.1-point change is equal to a 10% difference. Index values allow for comparison of change across indicators with different units of

Barley is predominantly grown in the north and west of the country with the highest planted acreage in North Dakota, Montana, and Idaho in 2020. There were clear improvements over time in land use, energy, and greenhouse gas (GHG) emissions with a plateauing of soil erosion and irrigation water use in the past two decades.

measure. A smaller area represents improvement over time.

Corn (Grain)

The highest acreage of corn harvested for grain occurs in the Midwest states of Iowa, Illinois, Indiana, Minnesota, and Nebraska with production area in South Dakota and Kansas increasing over the past 15 years. Corn grain improved over time in most indicators with that improvement slowing over time and stalling for soil erosion in the 2010s.

Corn (Silage)

A producer may decide partway through the season to harvest the corn crop as silage, rather than wait to harvest as grain, depending on market and weather conditions. Silage corn is grown in almost every U.S. state with high production in the upper Midwest states and other large dairy states, including New York, Pennsylvania, and California. Corn silage showed overall improvements in energy use and land use, but there has been a recent reversal in the energy use trend and a fluctuation over time in irrigation water use. Note that the soil erosion indicator for corn silage is the same data as presented for corn grain.

Cotton

Cotton is predominantly grown throughout the southern U.S. with the most acreage historically in Texas. Cotton steadily improved over time in energy use, GHG emissions,

and irrigation water use with recent trends since 2010 stalling in soil erosion and land use.

Peanuts

Peanut production in the United States is concentrated in the South, with large acreage in the states of Georgia, Texas, and Alabama and with Florida and the Carolinas also contributing significant acreage at different times over the past 40 years. Peanuts offered mixed results, representing a lack of clear trends over the study period. Values for energy use, GHG emissions, and land use for the most recent period (2010–2020) are considerably lower than previous periods while soil erosion and irrigation water use have seen more moderate improvements.

Potatoes

Potatoes are grown in many different regions of the country, with the largest acreage in northern and western states, including Idaho, Washington, North Dakota, Colorado, and Wisconsin. Overall, potato production has become concentrated into fewer states over the study period. In potatoes, the most recent decade has seen improvements across all indicators, with some mixed trends over the previous decades.



Cotton planted into a cereal rye cover crop. Photo by Annu Kumari.

Rice

Rice is primarily grown in two regions of the United States—the Sacramento–San Joaquin Delta region of California and the Mississippi River valley states of Arkansas,

Louisiana, Mississippi, Texas, and Missouri. The largest share of planted acres is in Arkansas with 48% of rice acres in 2020. Rice demonstrated overall consistent improvement in land use and GHG emissions with improvement in irrigation water use recently plateauing and mixed results for energy.

Sorghum

Sorghum is a drought-tolerant crop grown primarily in the Central Plains states, where nearly 70% of sorghum was planted in 2020; the remaining planted acreage was in Texas. Over the study period, the region of production has become more tightly centered on these states with only six states producing sorghum in 2020 compared with 24 states in 1980. Sorghum shows mixed results across indicators with the highest values for land use, emissions, and energy use in the 2000s; soil erosion in the 1980s; and irrigation in the 1990s.

Soybeans



Irrigation in a peanut field. Photo by Peggy Greb (USDA-ARS).

Soybeans are widely grown throughout the eastern half of the country with the greatest production in Iowa, Illinois, Indiana, Missouri, and Minnesota. Over time, a larger share of acreage has shifted farther west into the Dakotas and Nebraska. Soybeans show clear improvement from 1980–2000 across the indicators with progress slowing in the past

two decades. Land use and irrigation water use efficiency saw the greatest improvements over the last two decades while little or no improvements were observed for soil erosion, energy use, and GHG emissions.

Sugarbeets

Sugarbeets are a root crop grown predominantly in cooler climates. Areas of production are concentrated in northern states and the Mountain West with the largest acreage in Minnesota, Michigan, North Dakota, and Idaho. Sugarbeets demonstrated steady improvement for land use, energy use, and GHG emissions indicators as well as improvement over the study period for irrigation. Unfortunately, there is a lack of key, up-to-date data for sugarbeets. For example, crop protection and fertilizer usage were last surveyed in 2000. The late 2000s were an important time period as a new variety of genetically engineered sugarbeet was introduced and adopted almost universally by U.S. sugarbeet growers in 2009–2010 (USDA–APHIS, [2020](#); USDA–ERS, [2021](#)). This variety requires fewer crop chemical inputs; however, no surveys on chemical use have been conducted after this transition period, so we are unable to fully quantify environmental impacts related to sugarbeet production. For the fourth edition of the *National Indicators Report*, sugarbeet yield units are expressed in tons of sugar rather than raw tons. The sucrose percent data reported by USDA was used to calculate this adjustment.

Wheat



Across crops, increases in fertilizer and crop protectant use in the past 10 years emerges as a key

Across the U.S., wheat production acreage is greatest in the Central Plains, including Kansas, Texas, the Dakotas, and Montana.

contributing factor to the increasing energy use and greenhouse gas emissions trends. Photo courtesy of fotokostic/iStock.

Wheat shows improvement in the 2010–2020 period compared with 1980–1990 for all indicators with the greatest improvements in land use, irrigation water use, and energy use.

Summary

There are some common themes that begin to emerge when looking across the full scope of the indicator results:

Across crops, increases in fertilizer and crop protectant use in the past 10 years emerges as a key contributing factor to the increasing energy use and GHG emissions trends. Efforts to improve on input use efficiency have not yet reached widespread effectiveness.

Reductions in GHG emissions per acre have only occurred for crops that are using less N fertilizer over time.

Soil erosion improvements were greatest from 1990–2005, accounting for most of the gain for all crops. Soil loss uniformly increased or held steady in the 2010s. This may reflect the generally flat recent trend for adoption of no-till and reduced-till practices and the relatively modest adoption of cover crops to date. Understanding why conservation tillage adoption has plateaued will be key to understanding what is needed to drive greater adoption and future improvements in soil conservation.



No-till. Photo courtesy of the United Soybean Board.

As we have noted throughout this study, the trends identified are defined by available national scale data. In some instances, there are potentially important drivers of trends that cannot be incorporated into the analysis due to missing information. We discuss data limitations further in Appendix A of the full report.

Overall, the indicator findings extend the trend that was noted in the third edition of the report (Field to Market, [2016](#)) of a plateauing of the progress made in the 1990s and early 2000s. While the agricultural industry and research to develop new technologies is critical to success, it is increasingly clear that there are also social science and community-level factors that contribute to sustained change.

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