Field to Market®

National Indicators Report: Environmental and Socioeconomic Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States

Third Edition | December 2016

Field to Market: The Alliance for Sustainable Agriculture

Field to Market is a leading multi-stakeholder initiative that brings together a diverse group of grower organizations; agribusinesses; food, beverage, restaurant, and retail companies; conservation groups; universities; and public sector partners to focus on defining, measuring, and advancing the sustainability of food, fiber, and fuel production in the United States. A full list of members is available at www.fieldtomarket.org.

Credits

Contributors

The primary contributors to this report were Allison Thomson, Field to Market; Grant Wick, Field to Market and Colorado State University; Stewart Ramsey, IHS Markit; and Brandon Kliethermes, IHS Markit.

Editor

Betsy Hickman, Field to Market

Expert Reviewers

- Becky Chaplin-Kramer, Stanford University
- Bruno Basso, Michigan State University
- Chris van Kessel, University of California, Davis
- Doug Karlen, U.S. Department of Agriculture, Agricultural Research Service
- Marcel Aillery, U.S. Department of Agriculture, Economic Research Service
- Patricio Grassini, University of Nebraska, Lincoln
- Tristram West, U.S. Department of Energy
- William Edwards, Iowa State University

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Executive Summary

Field to Market: The Alliance for Sustainable Agriculture brings together a diverse group of grower organizations; agribusinesses; food, beverage, restaurant, and retail companies; conservation groups; universities; and public sector partners to create opportunities across the agricultural supply chain for continuous improvement in productivity, environmental quality, and human well-being. Field to Market offers America's food and agriculture industries an essential tool for unlocking shared value for all stakeholders—a common framework for sustainability measurement that farmers and the supply chain can use to better understand and assess performance at the field, local, state, and national levels.

By linking the entire agricultural value chain together to collaborate pre-competitively, Field to Market helps drive continuous improvement in the sustainability of commodity crop production. Our Supply Chain Sustainability Program provides an unparalleled platform that helps the food and agricultural supply chain benchmark sustainability performance, catalyze continuous improvement, and enable brands and retailers to characterize the sustainability of key sourcing regions as well as measure and report on progress against environmental goals.

This, the third edition of our National Indicators Report, analyzes sustainability trends over time at the national scale for commodity crops, utilizing the eight environmental indicators in Field to Market's Supply Chain Sustainability Program and five additional social and economic sustainability indicators. Utilizing publicly available data, published government reports, and scientific literature, we take stock of long-term trends from 1980 to 2015 to assess the sustainability performance of commodity crop agriculture against these indicators.

This edition updates the national level indicators presented in the previous reports for Land Use, Soil Conservation, Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions. In addition, we include the six crops previously assessed: corn for grain, cotton, potatoes, rice, soybeans, and wheat, as well as four new crops: barley, corn for silage, peanuts, and sugar beets. This edition also includes three environmental indicators not considered in the previous report—Biodiversity, Soil Carbon, and Water Quality. Without sufficient quantitative data for these three indicators, we are unable to evaluate crop-specific national trends. However, extensive research and evaluation of national level government reports and scientific literature have enabled us to explore what sustainability trends can be evaluated for each of these three important sustainability issues for commodity crop production as a whole. While we present and discuss trends and drivers, it is important to note that a full statistical analysis for attribution to specific drivers and establishing significance is beyond the scope of the report.

This edition updates the same six social and environmental indicators evaluated in the second edition, utilizing publicly available data to establish a national trend for five indicators, which are Farm Financial Health, Farm Profitability, Generation of Economic Value, Worker Safety, and Labor Productivity.

What We Learned: Report Findings

- All primary environmental indicators for Land Use, Soil Conservation, Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions, with the exception of Soil Conservation for peanuts, show improved environmental performance in 2015 when compared directly to 1980.
- In many cases, improvement in environmental performance was largely driven by increases in crop yield when evaluating per unit of production. The results are more variable when environmental performance per acre is assessed or when total resource use is considered.
- Confidence in trends is highest in cases where the trend lines for both per-unit production and per-acre production illustrate consistent improvement.
- In a number of crops, according to both environmental and economic indicators, there is a clear trend toward a plateau, or flattening, of the long-term trend line over the past five to 10 years, presenting both a challenge and opportunity for technological innovation combined with expanded adoption of conservation practices.
- National trends assessed for Biodiversity, Soil Carbon, and Water Quality highlight the complexity of assessing indicators that result from complex human interactions with the environment; while some limited trends can be discerned from available information, clear long-term signals would require additional data and advances in scientific research.
- The socioeconomic indicators for Farm Financial Health and Worker Safety improved over their respective time periods, while the Labor Productivity indicator indicated improved efficiency of production. The Farm Profitability and Generation of Economic Value indicators illustrate that the agricultural sector's contribution to national GDP has increased over the time period evaluated.

Environmental Indicators by Crop

BARLEY

Total production and area planted of barley have declined significantly over the study period, while yields have increased. The Land Use, Soil Conservation, and Irrigation Water Use indicators improved consistently over time, while Energy Use and Greenhouse Gas Emissions improved slightly on a per-bushel basis and increased slightly on a per-acre basis.

CORN FOR GRAIN

Area planted and total production of corn continued to increase through the study period, and the Land Use indicator also continued to improve. For the other four primary indicators, the declining (improving) trend transitioned to a flat trend in the early to mid- 2000s, indicating that the improvements in environmental outcomes on a per-bushel basis have plateaued.

CORN FOR SILAGE

Total production of corn for silage has increased slightly, while total planted area declined slightly from 1980 to 2015. The Land Use, Energy Use, and Greenhouse Gas Emissions indicators have all improved steadily over the past 36 years; however, Energy Use and Greenhouse Gas Emissions have increased on a per-acre basis. Irrigation Water Use increased in the first 15 years of the study period, before beginning to decline (improve) after 2000.

COTTON

There is variation but no consistent trend in the total production and area planted for cotton. The Land Use, Energy Use, and Greenhouse Gas Emissions indicators have all improved over time on a per-pound-of-lint basis, while Irrigation Water Use has improved (declined) steadily on both a per-pound and per-acre basis.

PEANUTS

Total production of peanuts has increased over time, with a slight decline in planted area. All indicators, with the exception of Soil Conservation, improved over time on a per-pound basis. Soil Conservation increased until around 2007, when it began to decline (improve).

POTATOES

Total production of potatoes has increased, while planted area has declined; however, the Land Use indicator has remained relatively flat since 2000. While all four of the other indicators have improved over time on a per-hundredweight (cwt.) basis, Energy Use and Greenhouse Gas Emissions have increased on a per-acre basis. Irrigation Water Use has declined consistently both per cwt. and per acre. These indicators all continue trends past the year 2000, indicating that the trends are driven by factors other than yield.

RICE

Total production of rice has increased slightly, while planted area has remained steady. The Land Use indicator has improved over time but remained steady for the past four years. This coincides also with a plateauing of the Energy Use, Irrigation Water Use, and Greenhouse Gas Emissions indicators, signaling that improvements over time have been driven in large part by yield improvements. Soil Conservation declined (improved) after the early 2000s.

SOYBEANS

Both total production and planted area of soybeans have increased from 1980 to 2015. Yield improvement, illustrated in the Land Use indicator, has driven improvements in Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions on a per-bushel basis, and these indicators have increased slightly on a per-acre basis. For these indicators as well as Soil Conservation, the improvement trends have become flat trends in recent years.

SUGAR BEETS

Total production of sugar beets has increased as planted area has remained relatively steady. The Land Use indicator has improved over time, along with the Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions indicators on both a per-ton and a per-acre basis. Soil Conservation has not followed a consistent trend over time but rather shows variation, with a slight improvement in the past five to 10 years.

WHEAT

Both total production and area planted have declined over time, while the Land Use indicator illustrates improvements in yield. The Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions indicators have all improved on a per-bushel basis, with either steady or increasing per-acre trends. The Soil Conservation indicator shows consistent declines (improvement) over time.

National Trends in Environmental Indicators

In Part Two of this report we include, for the first time, a discussion of three environmental sustainability outcomes for which calculating a national trend line by crop is not possible given both available data and the nature of the environmental outcome.

BIODIVERSITY

Assessing suitable land available for habitat to support a diverse ecosystem, we evaluated long-term trends in land cover change. From 1980 to 2000, agricultural lands (for all crops) decreased in area as they were converted to grasslands (including those grasslands in USDA's Conservation Reserve Program, or CRP), urban land, and forest land, according to comprehensive national analyses using satellite remote sensing data. While no comprehensive national land cover change analysis is available after 2000, recent remote sensing studies have found increasing cropland area in some regions, reflecting expansion of row crops into previously set-aside CRP lands and grasslands. New technologies and scientific advances show promise for future assessments of land cover change that are ecosystem- and land management system-specific.

SOIL CARBON

We have assessed trends in soil carbon, which indicate a negative change between 1990 and 2007 on aggregate (more carbon was lost than gained) for commodity crop systems using data from national modeling studies conducted for government assessments. The exception is land that is in complex rotations, or perennial grass (hay or CRP land). When these are considered, the overall national trend is consistently positive (increasing carbon in soils).

WATER QUALITY

While an aggregate nationwide measure or assessment of water quality trends is not available, we analyzed government reports on water quality in major watersheds from in-stream measurement programs and from a simulation modeling scenario of conservation practice adoption to assess the state of water quality and agriculture nationally. While conservation practice adoption has likely helped to avoid substantial nutrient, sediment, and pesticide loss to waterways, in-stream water quality measurements have not notably improved in recent years. We find encouragement in recent research that has found that continued adoption of conservation practices holds promise to improve water quality outcomes over the long term.

EXECUTIVE SUMMARY

Socioeconomic Indicators

We continue to explore socioeconomic indicators in Part Three of the report in order to gain a better understanding of the long-term trends in economic sustainability and social well-being associated with commodity crop production in the United States.

GENERATION OF ECONOMIC VALUE

Measured by the contribution of all agriculture to the national gross domestic product, commodity crop production has increased the generation of economic value over the period of 1997–2015.

FARM FINANCIAL HEALTH

Measured by the debt-to-asset ratio for general cash grain farms, Farm Financial Health has improved over the period of 1996–2015, driven by strength of land value and relatively low farm debt.

WORKER SAFETY

Improvements in all measures of the Worker Safety indicator—workplace injury, time lost from work due to illness, and workplace fatalities—improved (decreased) over the period analyzed.

FARM PROFITABILITY

Crop-specific Farm Profitability represents the financial returns to a farmer above the variable costs of their operation. No clear national trends can be drawn, as substantial variation exists between crops as well as over time due to numerous cost factors and crop price trends.

LABOR PRODUCTIVITY

Improvement over time in the Labor Productivity indicator is seen for most crops as a decline in the number of hours per acre and per unit of production; for most crops, this improvement has plateaued in the last five to 10 years.

Conclusions

The findings in this report highlight both the opportunities and the challenges of achieving continuous improvement in environmental outcomes of agricultural land. On the whole, the crops assessed have produced more yield on less land with improved environmental outcomes on a per-unit-of-production basis. This continued improvement has also contributed to reduction in loss of soil carbon. This significant progress toward more sustainable food, feed, fiber, and fuel production is a result of many different technological advancements and greater adoption of conservation practices.

However, this report identifies that improvements are plateauing for a number of crops and indicators. Moreover, recent studies indicate an increase in crop land area in certain regions of the country at the expense of grasslands and other ecosystems and highlight continued water quality challenges in many river basins. To continue to improve on these very challenging and pressing sustainability concerns will require not just concerted action from farmers but collective action from the agricultural agencies, communities, and supply chains that support them. Identifying important technology improvements that can address these environmental sustainability outcomes is one area to target. Another is further research on effective conservation practices and the necessary infrastructure, training, and knowledge transfer to increase their adoption by farmers across the country.

In some areas, achieving continuous improvement is also limited by knowledge gaps that require redoubling efforts on scientific research. In particular, better understanding of the fate of nutrients and the most effective practices for ensuring efficient use and minimal loss of nutrients to the environment is critical. While studies indicate the potential for water quality improvement due to conservation practice adoption is substantial, this improvement has not been observed in the nation's waterways.

These limitations also present opportunities for supply chain partners to advance sustainable agriculture through communicating the importance of this data and research to the private sector. Downstream companies and retailers can provide a consistent signal to the supply chain and farmers that improvement in these sustainability trends over time is important to customers. Similarly, it is essential that this demand signal be consistently sent regardless of end use, whether for food, feed, fiber, or fuel.

In the same way, the agriculture community can provide support to farmers in the form of knowledge and guidance for specific farming operations by coordinating and sharing knowledge among commodity organizations, agricultural retailers, crop advisors, and university extension personnel. Field to Market is working with organizations along this spectrum of opportunities to support development of education and outreach guidance for both farmers and supply chain partners to advance opportunities for continuous improvement.

At the core of all the trends and improvements illustrated by the indicators presented are the millions of individual decisions made by farmers and land managers every day. Analyzing the aggregate impact of these decisions underscores the critical importance of individual actions in achieving improvements and delivering sustainable outcomes for agriculture and the environment. The field-scale metrics and benchmarking available in the Fieldprint® Platform—the analytic engine that drives the metrics in both the Fieldprint® Calculator and the integration into associated farm management software—provide a way for farmers and the supply chain to characterize their sustainability and identify opportunities for improvements at the field and landscape levels. By catalyzing continuous improvements at the field level, Field to Market's members are working together to drive significant and broad-scale progress nationally toward creating a more sustainable food system.

Introduction

In the coming decades, global population increases will lead to increased food, feed, fiber, and fuel demands. To be sustainable, these demands must be met with increased efficiency and intensification of existing systems [1, 2, 3]. At the same time, a changing and more variable climate will present new challenges to farmers [4]. This multitude of challenges requires engagement in coordinated efforts by all stakeholders in the food and agriculture system [5] to ensure that environmental sustainability and increased productivity are both achieved.

Recently, research has begun to focus on the potential strategies for sustainable intensification of agricultural crops while simultaneously lessening the impact on the environment [6, 7, 8]. Field to Market: The Alliance for Sustainable Agriculture focuses on defining, measuring, and advancing continuous improvement in the sustainability of U.S. commodity crop production. The U.S. has abundant and productive cropland, making it one of the most critical regions of the world for ensuring future food security; at the same time, significant use of water, nutrients, and other scarce natural resources used to produce food, fiber, and fuel illustrates there is still room for improvement in efficiency to help sustainably intensify agricultural production [9, 10]. While adoption of conservation practices has increased markedly in recent decades across the country, rates of adoption vary widely across regions and crop systems, and significant opportunities remain for increased uptake [11]. Conservation agriculture practices hold promise to address many of the sustainability challenges facing U.S. agriculture [12].

Field to Market was formed a decade ago by a group of concerned stakeholders across the commodity crop supply chain who recognized that the challenges facing food and agriculture were bigger than any one organization could tackle alone. As a multi-stakeholder initiative, the development of Field to Market began with and continues to represent the perspectives of farmer-led grower organizations; agribusinesses providing products and services to farmers; food, beverage, restaurant, and retail companies producing products for consumers; conservation organizations representing critical societal and sustainability concerns; and university and public sector partners bringing objective science and technical expertise to the discussion. These diverse stakeholders find common ground in a desire to address the global challenge of continuing to provide sufficient food, feed, fiber, and fuel for a growing population while conserving our natural resource base and preparing agricultural production to adapt to future environmental challenges. Together they have built a framework for defining, measuring, and advancing sustainable agriculture that is grounded in science and focused on continuously improving the environmental outcomes of commodity crop production at the field level.

Field to Market defines sustainable agriculture as a system that meets the needs of the present while improving the ability of future generations to meet their own needs by increasing productivity to satisfy future food, fiber, and fuel demands and improving the environment, human health, and the socioeconomic well-being of agricultural communities. Over the past decade, Field to Market has refined its focus to eight critical environmental outcomes that serve as indicators of sustainable agriculture:

- Biodiversity
- Energy Use
- Greenhouse Gas Emissions
- Irrigation Water Use
- Land Use
- Soil Carbon
- Soil Conservation
- Water Quality

We also evaluate five socioeconomic indicators at the national scale: Farm Financial Health, Farm Profitability, Generation of Economic Value, Worker Safety, and Labor Productivity. This report assesses the national trends in the U.S. for these eight environmental and five socioeconomic outcomes through a set of national level indicators based on publicly available data. Field to Market's programmatic goals establish the objectives for each outcome.

Our Goals

Field to Market is working to meet the challenge of producing enough food, fiber and fuel for a rapidly growing population while conserving natural resources and improving the ability of future generations to meet their own needs. The organization and its members recognize that a critical component of any sustainability goal is the maintenance of economic viability. Field to Market will provide useful measurement tools and resources for growers and the supply chain that track and create opportunities for continuous improvement. Our efforts are guided by the following goals:

- **Energy Use—**Sustained improvement in energy use efficiency from U.S. crop production
- **Greenhouse Gases—**Sustained reduction in greenhouse gas (GHG) emissions from U.S. cropland per unit of output, and sustained contribution to addressing the overall GHG emissions from agriculture, recognizing the need to meet future crop production demands
- **Irrigation Water Use—**Sustained contribution to solving regional water scarcity problems through continual improvement in irrigation water use efficiency and conservation
- **Land Use—**Sustained improvement of land use efficiency by increasing productivity on U.S. cropland, conserving native habitat and enhancing landscape quality
- **Soil Conservation—**Sustained reduction in soil erosion to tolerable levels or below on all U.S. cropland
- **Water Quality—**Sustained contribution to solving regional water quality problems as evidenced by reductions in sediment, phosphorus, nitrogen and pesticide loads from U.S. cropland.

Field to Market will promote a research agenda to address questions about the ability of U.S. agriculture to achieve:

- Absolute GHG emissions reductions, accounting for soil carbon sequestration and other advances in accounting for GHG emissions in crop production
- Conservation of native habitat, enhancement of landscape quality, and improvement of conservation outcomes
- Overall maintenance and improvements to soil health

To achieve these goals, Field to Market will seek to engage 20 percent of productive acres of U.S. commodity crop production in its supply chain sustainability program by 2020. To measure progress against these goals, outcomes will be measured and reported based on a five-year rolling average.

While this report seeks to provide a national trends assessment, the eight environmental outcomes can be measured at the field scale by use of the Fieldprint® Platform, either online through the Fieldprint® Calculator or through associated farm-management software that integrates Field to Market's sustainability metrics and algorithms. Farmers can use these metrics to calculate their Fieldprint® analysis, which benchmarks their sustainability performance, helping identify areas for improvement and tracking improvement over time in the eight sustainability outcomes.

The overall objectives of the 2016 report include:

- Analyzing trends over time in sustainability performance for U.S. commodity crop systems
- Creating enabling conditions for stakeholders in the U.S. to contribute to discussion and development of sustainable agriculture metrics and their application toward advancing sustainable practices
- Advancing an outcomes-based approach that is grounded in science to define and measure agricultural sustainability, which can be adapted for other geographies and crops

The report is divided into three sections, exploring both environmental and socioeconomic trends in sustainability performance for U.S. commodity crop production. Part One includes calculation of national scale indicators for five of the outcomes (Energy Use, Greenhouse Gas Emissions, Irrigation Water Use, Land Use, and Soil Conservation) for 10 crops (barley, corn for grain, corn for silage, cotton, peanuts, potatoes, rice, soybeans, sugar beets, and wheat). Together, these crops account for approximately 27 percent of agricultural land (defined by USDA as all land in farms) in the U.S. in 2015. Part Two explores research on national-level trends in three of the outcomes in relation to agricultural systems: Biodiversity, Soil Carbon, and Water Quality. Finally, Part Three assesses national-level trends in key socioeconomic indicators of sustainable agricultural systems.

Field to Market's eight environmental indicators are divided into two sections based on data availability and character of national-level information available for each indicator. For the indicators in Part One and Part Three, we follow the methodology of the previous report [13]. For Part Two, the indicators represent more complex environmental outcomes that are more challenging to assess on a national scale. For this section, we rely on government reports and other peer-reviewed publications of ongoing research and explore the potential of using these resources to assess national-level trends.

Environmental Indicators

The five environmental indicators are designed to assess resource use efficiency of crop production at the national scale over the period of 1980–2015. This edition extends the trends analysis of previous reports to 2015 and now includes four additional crops: barley, corn for silage, peanuts, and sugar beets.

LAND USE

The environmental indicator for land use efficiency is intended to inform understanding of the sustainability of productivity and is very closely tied to crop yields, which are the key to achieving an economically sustainable farming operation. In addition, cropland in the U.S. today covers about 19 percent of land area and encompasses the most suitable agricultural regions of the country. Trends over time in land cover change are explored in Part Two of this report; the land resource base in the U.S. and globally has largely brought under cultivation the most productive lands. Thus, expanding agriculture onto previously uncultivated land may bring less productive lands into cultivation, requiring greater resource use to produce marketable yields. Land expansion for agriculture would also come at the expense of land currently valued for habitat and for other ecosystem services. Thus, maintaining and improving yields on existing cropland are critical both to maintaining economic sustainability and to producing other sustainability outcomes.

SOIL CONSERVATION

Soil is a key resource for crop production that is constantly forming and evolving based on land management and environmental conditions. Soils are highly variable throughout the country, having been formed over millennia by natural geologic and climatic processes. Some areas of the U.S., such as the Corn Belt, are renowned for deep and highly fertile topsoil. Conservation of soil involves conserving soil quantity and quality by avoiding nutrient depletion and salinization, and maintaining soil organic matter. Field to Market currently focuses the Soil Conservation metric on soil loss from wind and water erosive forces. Soil erosion occurs when the soil surface is exposed to water and wind, and while soil does continue to form, the rate of formation is much slower than typical rates of soil loss to erosion in agricultural systems [14]. Earlier this year, Field to Market explored the role of soils in sustainable agriculture and the potential of soil health-enhancing management strategies to help in preserving and protecting the soil to maintain and increase productivity [15]. The Soil Conservation indicator included in this report is a high-level assessment of the rate of soil loss from cultivated lands. Sustainable agriculture strives to improve soil conservation by reducing erosion in order to preserve healthy soils for future years and generations of productivity.

IRRIGATION WATER USE

Water is an important limiting factor for crop production; without an adequate and timely water supply, crop yields are lower and highly variable across years [16]. In many regions of the country, water from precipitation is not sufficient or does not occur at the right time for optimum plant growth and crop yield. Irrigation allows producers to provide water to achieve high and stable yields [17]. Agriculture is the single largest consumptive user of water in the U.S. [18] and is consequently the sector most vulnerable to changes in weather and climate [19] and to depletion of groundwater resources [20]. Water is becoming an increasingly scarce resource due to greater demands associated with population growth, urbanization, and accessibility [21, 22]. The Irrigation Water Use indicator included here assesses the overall efficiency of irrigation water applied in terms of the incremental improvement it produces in crop yield. This indicator is designed to consider the water factor most directly under the control of the producer—the efficiency of water supplied through irrigation. The indicator does not include a measure of water use efficiency from precipitation or on non-irrigated cropland, nor does it reflect the source of the water used for irrigation. As water becomes more scarce and precipitation more variable and uncertain, improvements in irrigation water use efficiency will be critical to maintain production and contribute to conservation solutions in water-stressed regions.

ENERGY USE

From the generation of electricity to power farm operations such as irrigation to the production of nitrogen fertilizer to the fuel used in farm equipment, agriculture uses energy in many forms. Numerous studies have estimated the energy use, both direct and indirect, from crop production at a point in time [9, 23, 24, 25, 26]. In this report, we assess the trends in energy use efficiency of crop production in the U.S. over the past four decades. This indicator evaluates the energy used annually for each crop and provides a measure of the efficiency of energy use relative to the amount of crop yield. Energy use is also an important indicator for evaluating the cost of production of a farm operation, and recent trends indicate farms are increasingly both producing and using renewable energy [27].

GREENHOUSE GAS EMISSIONS

Energy use results in emissions of greenhouse gases (GHGs) from combustion of fossil fuels. Other agricultural activities also contribute to GHG emissions, including gaseous losses of synthetic and organic nitrogen fertilizers as nitrous oxide (N_2O) emissions from the burning of crop residues in the field, and methane (CH_4) emissions from fields flooded for rice production.

GHG emissions globally from all human activity are leading to changes in the Earth's climate system; these changes are already observed and will continue at an unknown degree as long as the concentration of long-lived GHG in the atmosphere continues to increase [4]. Agriculture will need to adapt to these changes in climate and weather patterns, and can also be part of the solution in reducing GHG emissions through climate-smart agriculture practices. The U.S. is a party to the United Nations Framework Convention on Climate Change and produces an annual report of GHG emissions from all sectors [28]. Total GHG emissions from crop cultivation—including methane from rice cultivation and nitrous oxide emissions from soils—represented roughly 60 percent of emissions from the U.S. agriculture sector; livestock was the remaining largest source. Agriculture as a whole contributed 7.7 percent of total national GHG emissions in 2015. These estimates do not include energy use on farms, which is accounted for in other sectors in the U.S. inventory report. At the same time, conservation agriculture practices can contribute to reducing the overall U.S. net emissions by storing, or sequestering, carbon in soils [12]. Improving soil carbon is also a key strategy for enhancing soil health [15], which can also enhance the land's resilience to extreme weather events. Soil carbon sequestration is also an important factor in reducing the net GHG emissions from crop production. While this indicator does not include this soil carbon, we explore what is known about national trends in Part Two.

Overall, these five indicators, when calculated at a national scale, provide a snapshot of the changes over time in the efficiency of crop production. Steady increases in crop yields are an important driver of improved efficiency, resulting from the adoption of sound science, conservation practices, and technological advances [29, 30]. Whether and to what extent these improvements in yield can continue into the future will be a key determinant for future improvements and for the future of sustainable agriculture [12].

National Trends in Land Use and Management

The five areas described above for which Field to Market has developed national scale indicators have been assessed in prior reports. They share the common theme of assessing overall efficiency as well as total resource use in agricultural production. However, sustainable agriculture is broader than efficiency, and Field to Market's goals include several additional sustainability concerns and objectives for the program. As a result, an effort to assess national trends in these additional sustainability areas is made in Part Two of this report.

The three areas—Soil Carbon, Water Quality, and Biodiversity—are complex outcomes of agricultural management and not suited to assessment through a framework of efficiency. Rather, they represent key environmental impacts of agricultural management decisions that must be considered in order to have a complete view of agricultural system sustainability and appropriately consider trade-offs. While these are not assessed in the five indicators described above, they are included in a separate section that evaluates available information on national scale trends over time.

SOIL CARBON

In addition to comprising an important component of the overall GHG balance of agricultural activity, soil carbon is also directly tied to the sustainability of crop productivity. Because soil carbon is a long-term characteristic of soils, the monitoring, maintenance, and enhancement of soil carbon are critical for keeping farmlands productive and limiting expansion of farmland while continuing to provide sufficient food, feed, fiber, and fuel. As the Greenhouse Gas Emissions indicator described above does not currently consider soil carbon, we evaluate results on soil carbon change for U.S. agriculture from an ongoing USDA simulation modeling exercise that is the basis of the national GHG inventory [28].

WATER QUALITY

A key environmental outcome from agricultural production, water quality also has important implications for society at large. Beyond the efficiency of water use assessed in the Irrigation Water Use indicator, water in the nation's streams, rivers, and estuaries is impacted by agricultural practices in complex ways. Both sediment from soil erosion and nutrients from fertilizer applications can be transported from fields to surface or groundwater. This runoff can accumulate downstream, leading to environmental concerns such as high nitrate levels in drinking water and the eutrophication of coastal regions, which deprives aquatic ecosystems of oxygen, causing detrimental impacts on ecosystems and fisheries. Many complex environmental and land and water management actions influence water quality. These vary substantially across regions of the country, and therefore a national level aggregate metric is not appropriate to assessing trends. In Part Two, we explore the findings of the U.S. Geological Survey from ongoing water quality monitoring programs and a USDA study on the effects of conservation practices on water quality outcomes, to assess trends for major U.S. river basins. These ongoing measurement and modeling efforts by the public sector provide a means to begin to understand trends and drivers in water quality outcomes.

BIODIVERSITY

An environmental outcome with larger societal consequences, biodiversity is influenced by farm management yet is also highly regional and not amenable to a national level aggregate indicator. Field to Market's programmatic goals highlight the importance of landscape quality for native habitat. As a result, we explore the trends in a key consideration for habitat: land cover change over time. By exploring national reports and scientific literature utilizing remote sensing imagery products from the past few decades, it is possible to identify trends in land cover that are important considerations for wildlife habitat and can therefore serve as a proxy indicator for biodiversity.

Consideration of these three additional environmental indicators in Part Two is a first attempt by Field to Market to assess these trends at a national scale. This effort highlights the available resources, the challenges in data availability and in identifying trends, and the limitations of previous analyses in developing markers by which national trends can be evaluated for continuous improvement.

Socioeconomics

Part Three of this report provides an update of the social and economic indicators for sustainable agriculture first reported in the previous report [13]. A critical component of sustainability is ensuring the health and economic well-being of agricultural workers and communities. The five indicators were developed based on publicly available data at the national scale, including three indicators of economic sustainability: Farm Financial Health (debt-to-asset ratio), Farm Profitability (return above variable cost), and Generation of Economic Value (gross domestic product or GDP); and two of social sustainability: Worker Safety and Labor Productivity. These indicators represent important trends in the agriculture sector for long-term sustainability. Farming operations that are economically sustainable and healthy for workers are better positioned to pursue efforts to ensure environmental sustainability.

Local Sustainability Driving National Trends

Tracking national trends in environmental and socioeconomic sustainability is important for assessing the overall sustainability of agricultural production. However, the drivers of the national trends assessed here are the result of individual farmers acting on their own fields to adopt conservation practices and make farming decisions that account for the impact on long-term sustainability from production on their land. Throughout this report we use the term "conservation practices" to identify a range of practices adopted by farmers with the objectives of improving efficiency and ensuring longevity in their operations while also reducing environmental impacts. What is considered a conservation practice varies by region and crop system; not all practices are appropriate to all conditions. In general, such practices as reducing or eliminating tillage, adopting nutrient management practices that reduce the potential for nutrient loss, adopting buffer strips or edge-of-field treatments to provide habitat or structures that reduce sediment runoff, and adopting rotational systems or cover crops to add diversity are examples of what can be considered conservation practices.

In order to assist producers in evaluating their management decisions for the environmental outcomes associated with them, Field to Market developed and maintains the Fieldprint® Platform, the engine that powers the Fieldprint® Calculator (a free, online tool) and the application programming interface that integrates Field to Market's sustainability metrics into existing farm management software. The Fieldprint® Platform can be used for evaluating field-level environmental outcomes for the crops in Field to Market's Supply Chain Sustainability Program. By entering their field information, producers receive scores for each metric along with additional context for how to evaluate their performance over time. In 2015, more than 1,480 farms covering approximately two million acres were assessed using this tool. Most were enrolled through one of more than 50 Fieldprint® Projects sponsored by organizations along the commodity crop value chain with an interest and incentive to improve the sustainability of commodity crop production.

Throughout Parts One and Two of this report, we refer to the field-level metrics deployed by the Fieldprint® Platform to assist farmers and the supply chain in measuring and monitoring their environmental outcomes with a shared goal of continuous improvement in all eight environmental indicators. Where possible, the national-level trends indicators have been developed to be consistent in scope and methodology to the field-level metrics. As Field to Market moves forward toward the goal of an enrollment of 50 million acres in our program, we endeavor to use the power of the supply chain and the transparency of a multi-stakeholder process to make a meaningful, measurable improvement in the sustainability of commodity crop production at the national scale.

PART ONE: Environmental Indicators

METHODOLOGY

The environmental indicators presented here build on the previous two reports [13, 31] as well as ongoing development of the Fieldprint® Calculator. Five indicators are calculated for the past 36 years (1980–2015) and thus represent an additional four years of data to the previous report. The overall methodology is detailed in this section, with specific emphasis on new data sources, method changes, and available data. In addition, we include four additional crops in this report, representing the expansion of the Field to Market program overall.

Field to Market first produced a national indicators report in 2009, thus beginning an evaluation of the broad environmental trends in commodity production. The calculations developed for that initial report served as the foundation for the field-level Fieldprint Calculator. Methods for both the report and the Calculator were substantially revised in the 2012 update. While the overall methodology is similar, the Fieldprint Calculator is intended for use at a field scale, and thus the metrics were developed with the ability to handle additional specific management information. For example, the national-level indicators reported here consider the average of tillage systems for the whole country; the metrics can account for the actual specific tillage system on an individual field. In addition, with field-specific information, the Fieldprint Calculator can call on other models to calculate specific metrics. This is the case with Soil Conservation, which is calculated by the NRCS models RUSLE2 and WEPS. The Soil Conservation indicator reported here is then based on simulation results provided by the USDA National Resources Inventory [32].

Since the 2012 report, Field to Market has expanded the metrics to include separate simulations of Soil Carbon, Water Quality, and Biodiversity. These are key sustainability concerns highlighted in the goals statement, yet for which a national-level indicator is not easily calculated. Therefore, in Part Two of this report we provide a separate section to consider what can be discerned about national-level trends for these important indicators.

The five key environmental indicators described here and presented in the results are:

- Land Use (acres per unit of production)
- Irrigation Water Use (acre-inches of water applied per additional unit of production)
- Soil Conservation (tons of soil loss per acre)
- Energy Use (BTU of energy used per unit of production)
- Greenhouse Gas Emissions (pounds of carbon dioxide equivalent (CO_2e) per unit of production)

As in the previous reports, all indicators were calculated on a per-acre basis and as total resource use. Examining the results from three different dimensions is important to understand not just trends in the efficiency of resource use, but also the total resource use for agriculture. However, to align this report more closely with the Field to Market goals statement and the Fieldprint Calculator metrics, we focus the primary results discussion on these five resource indicators. The per-acre and total resource use graphics are included in Appendix A.

These indicators are calculated for the 10 crops listed in Table 1, including barley, corn for silage, peanuts, and sugar beets for the first time. The units of production are based on USDA standard values for dry weight [33].

Crop	Yield Unit	Description
BARLEY	bu.	Bushel, 48 lb. of barley grain per bushel
CORN (GRAIN)	bu.	Bushel, 56 lb. of corn grain per bushel
CORN (SILAGE)	ton	2,000 lb.
COTTON	lb. of lint	Pounds of lint
PEANUTS	lb.	Pounds (lbs.)
POTATOES	cwt.	Hundred weight (100 lb.)
RICE	cwt.	Hundred weight (100 lb.)
SOYBEANS	bu.	Bushel, 60 lb. of soybean seed per bushel
SUGAR BEETS	ton	2,000 lb.
WHEAT	bu.	Bushel, 60 lb. of wheat grain per bushel

Table 1.1: Crops included in the Environmental Indicators, and unit of production for analysis.

Methods for calculating the indicators are standardized as closely as possible across crops and use publicly available data sources reported at the national scale. By focusing on the national scale, we capture long-term trends due to both changes in management practices and shifts in the location of production. Where national averages are constructed through the aggregation and weighting of various practices and geographies, the weighting was typically performed on a planted-acre basis. Exceptions include where data were based on total production, weighting was conducted based on production.

Throughout the methodology, we opted to use linear interpolation to complete a time series for certain data points only available in certain survey years. While the USDA National Agricultural Statistics Service (NASS) collects annual data on crop yield, production, and area, other data on irrigation amounts and technologies, crop tillage practices, and nutrient and crop protectant applications are only surveyed in certain years. As these surveys are not coordinated to occur in the same year, completing a full data series for all necessary variables for all indicators is not possible. In order to have internal consistency in the calculations, therefore, we opted to fill in the non-survey years using a simple and consistent methodology before calculating the indicators. This assists in our primary objective of identifying long-term trends but introduces uncertainty in the indicator values for any one specific year.

In addition, the annual crop yield data used in the calculation of the indicators are first adjusted to represent a five-year moving average. Thus, the crop yield for 1995 will represent the average yield for 1993–1997, and so forth. This reduces the impact of single-year events on crop yield, such as drought or other climate disruption, and helps to reduce the noise in long-term trends. For most crops, yields have increased over the 36-year period of analysis, and this improvement is a driving factor in many of the indicator trends presented here.

The methods described below also follow the 2012 report, which used planted acres, rather than harvested acres, to account for land in production [13]. The use of planted acres accounts for abandonment due to weather or other adversity that causes the crop not to be harvested. Therefore, it is a more comprehensive measure, particularly at the national scale, where crop abandonment is an important means of understanding the impact of losses on the overall efficiency of input usage and the relationship between impacts and productivity. The impacts of intentional land fallowing or double-cropping are not explicitly captured here.

The five indicators are calculated using simple algorithms (Land Use, Irrigation Water Use), complex algorithms (Energy Use, Greenhouse Gas Emissions), or more complex simulation models (Soil Conservation). While we have endeavored to use transparent methodology and the best available data, these indicators represent the best reflection of sustainability trends; however, as with any mathematical representation of the physical world, the results are subject to some uncertainty from both the available data and the methodology chosen. As we describe each calculation in detail below, we also indicate the sources of uncertainty in the data and methodology for each.

Corn for Grain and Silage

For the first time in this report we include both corn for grain and corn for silage. While these represent two different crop production systems with different downstream uses, the data collection and reporting for USDA do not always distinguish between the two production systems. Therefore, some adjustments are made based on the planted area estimates, which are provided for corn for grain and corn for silage separately.

The estimated percent abandonment for corn for silage and corn for grain are assumed to be equal, and estimated corn for silage planted area has been subtracted from USDA's total planted area for corn for all purposes. For reference, in 2011, 93 percent of corn harvested for all purposes was for grain.

Due to the nature of the National Resources Inventory (NRI) datasets used for the analysis, soil erosion rates for corn for grain and corn for silage were assumed to be equal [32]; however, considering differences in harvest practices for silage and grain, it is expected that, on average, erosion from corn for silage would be higher than that from corn for grain, all other things being equal [34]. Consequently, absolute levels of soil erosion for corn for grain may be slightly overestimated in this report, while those for corn for silage may be underestimated.

Co-products for Cotton and Wheat

The indicator methodologies also account for economic allocation of co-production of cottonseed (with cotton lint) and wheat straw (with wheat grain). The economic allocation formula determines the share of the primary product as a proportion of the total dollar value of product sold.

The five-year average from 2005 to 2009 was used. In the case of cotton, the share of the lint value divided by the lint plus seed values was determined to be 0.83 or 83 percent. Cottonseed is an economically important co-product of cotton and is a consistent component of income for all U.S. cotton producers. The 83 percent factor is then applied to the absolute level of a given resource:

Primary product share for cotton lint = lint value/(lint value + seed value associated with a pound of lint)

Primary product share for cotton lint = \$0.55/(\$0.55 + \$0.11) = 83 percent

The economic importance of wheat straw as a co-product of wheat varies in the U.S. by region and year [35], and the factor used here assumes 3.4 percent of the economic value of wheat is derived from the straw co-product.

Values representing wheat grain and cotton lint may be converted to values representing that required to produce all economic yield components by multiplying wheat (bu.) and cotton lint (lb. lint) by 1.034 and 1.17, respectively.

Land Use Indicator

The primary Land Use indicator considered here is the amount of land required to produce a unit of production (e.g., acre/bu.), and is the inverse of standard crop yield calculations. In addition, for each crop we report on the trends in total area planted and total production, and in Part Two we further consider trends in land cover change and the spatial distribution of agricultural land throughout the study period. The Land Use indicator follows the same methodology as the Land Use metric result from the Fieldprint® Calculator.

Annual yield per planted acre for each crop considered was downloaded from the USDA NASS Quickstats database [36], along with planted area and total production at the national scale. As indicated earlier, the annual crop yields were adjusted using a five-year moving average in order to reduce the impact of any one-year event on yields. The annual number provided by USDA is based on state and country crop yields aggregated according to standard USDA statistical sampling and procedures [36]. For some crops, the regions where they are grown in the U.S. are geographically small and relatively homogeneous (e.g., barley, peanuts), and thus even the national-level indicators are influenced by regional climate events.

This indicator is calculated using a simple algorithm, where the one data variable (crop yield) is known with a high degree of accuracy. Thus the uncertainty level for this indicator is low.

Soil Conservation Indicator

The Soil Conservation indicator represents soil erosion from wind and water erosive properties as calculated in simulation models by the USDA National Resources Inventory (NRI). The NRI erosion simulations rely on detailed farm management and environmental data gathered in USDA surveys from 1982 to 2012 in five-year increments. This indicator is therefore available only for seven of the 36 years in our time period of analysis (1982, 1987, 1992, 1997, 2002, 2007, 2012). We use a linear interpolation to complete the time series in order to be able to include this indicator on the summary graphics, and place it in the same context as the other four indicators.

The most recent available data for soil erosion are from the 2012 survey, released in 2015 [32]. The erosion results represent both water and wind erosive properties according to simulation model results. Each successive report provides a consistent methodology across the time series; thus, if changes are made to methodologies for aggregation, all previous years are recalculated. The NRI 2012 release updated the sheet and rill water erosion model used from the Universal Soil Loss Equation (USLE) to the Revised USLE, version 2 (RUSLE2) [38]. Wind erosion is also included, using the Wind Erosion Equation (WEQ), for selected states. The full results are presented in the 2012 report [32] at the national and state levels. The Soil Conservation metric in the Fieldprint® Calculator also applies the NRCS models for individual fields; it applies the RUSLE2 model for water erosion, and the Wind Erosion Prediction System (WEPS) model for wind erosion.

The primary Soil Conservation indicator reported here is in units of tons of soil loss per acre for each crop, which is the unit of simulation for the wind and water erosion models, and takes the national-level estimate from the NRI simulations. In addition to the primary indicator of erosion per acre, we also include a measure of total soil loss in Appendix B, obtained by multiplying the estimated soil erosion per acre by the planted acreage for each crop. The data required for the Soil Conservation indicator are complex and acquired based on statistically determined surveys every five years. The methods used in the calculation are complex models, or sets of algorithms, that depend on data, parameterization, and model calibration. Thus, the level of uncertainty for this indicator is moderate; given the use of best available data and methods in a consistent manner by USDA, we have reasonable confidence in the trends reported here.

The two previous reports [13, 31] also included a measure of soil erosion per unit of production (e.g., tons of soil loss per bushel). Considering environmental impact per unit of production allows consideration of the role of increasing crop yield on the efficient use of resources. However, the soil resource is different in character from resources considered in the other indicators. Soil is a finite resource for each individual field that is regenerated very slowly, over decades, and at a rate much lower than typical erosion rates [14]. By the Field to Market definition of sustainable agriculture, producers should strive for continuous improvement

(reduction) in the rate of soil erosion, regardless of crop yield trends. Practices that preserve and even regenerate soil on agricultural lands will increase the probability that high yields can be maintained [39]. Thus for both this indicator's report and the Fieldprint® Calculator, we have adopted the soil loss per acre as the primary measure of soil conservation.

Irrigation Water Use Indicator

The Irrigation Water Use indicator is intended to reflect the marginal return of crop yield based on water applied in irrigated systems. This indicator only applies to irrigated production; we do not include a water use indicator for rainfed production or consider the sustainability of the source water used for irrigation. Irrigated agriculture takes many forms in the U.S., determined by crop type, climate conditions, economic conditions, and regional water management rules. The indicator was developed to normalize across all these variables to consider how much production was gained from each incremental addition of water.

Irrigation water use is defined here as the anthropogenic application of water on land to satisfy crop water requirements and, by doing so, achieve high and stable yields. We confine our focus to irrigation water applied as a primary resource over which growers have direct control. To the extent that irrigation source and mechanism (e.g., gravity fed vs. pumping) drives energy use, these practices are captured in the energy use metric.

The Irrigation Water Use indicator is calculated as: IWU = irrigation amount (acre-inch)/(irrigated yield – non-irrigated yield).

The resulting value represents the amount of water for each incremental gain in crop yield. Data used in the calculation of the national indicator are taken from the USDA Farm and Ranch Irrigation Survey (FRIS), a component of the Census of Agriculture that is produced at five-year increments. These data are available for 1984, 1988, 1994, 1998, 2003, 2008, and 2013 and include national-scale estimates by crop of the amount of irrigation water applied per acre as well as the irrigated crop yield and the non-irrigated crop yield [40–44]. The FRIS survey calculates the national average irrigation rate by a weighted average using irrigated acreage and irrigation rate at the state level; however, we noted an anomaly in the state-level irrigated acreage information for rice in 2013 that resulted in a heavy overweighting of the irrigation rate in California in the national average rate. After consultation with USDA census staff (Steve Sakry, personal communication), we recalculated the national average irrigation rate for rice for 1984–2013 based on the state-level irrigation rate from FRIS and the planted area of rice at the state level from NASS.

The non-irrigated yield included in our calculations is also taken directly from national estimates reported in the FRIS survey. This is defined as yield from the same crop, grown in the same environmental and management conditions as the irrigated yield, and is referred to as "non-irrigated yield from farms equipped for irrigation." The value for non-irrigated yield is reported by the farmers responding to the FRIS survey and is typically based on either an estimate or the yield from a dry corner of an otherwise irrigated field. Thus, non-irrigated yield is distinct from rainfed yield (grown on farms with no irrigation systems). Rice and potatoes are assumed to be grown only in irrigated systems, and the non-irrigated yield is set to zero.

As these data points are available only in the selected census years, these were used to calculate the relationship between the average yield (from NASS, which represents both irrigated and rainfed production) and the irrigated and non-irrigated yields from FRIS. This relationship was then used to estimate the irrigated and non-irrigated yields for the intervening years, by adjustment of the NASS average yield, which is available annually [36] (FRIS survey staff, personal communication). Linear interpolation between FRIS census years was then used to establish the amount of irrigation water applied in non-census years. We recognize that this method to obtain annual irrigation amounts is highly uncertain, as it does not account for inter-annual variation in climate, which is a strong determinant of crop water yield. However, to ensure consistency and comparability of trends across indicators, we chose to report on the full time series of data even where linear interpolation was necessary to construct annual values.

The average share of land irrigated for each crop was also calculated, based on the total amount irrigated and the total planted area. This share was used to estimate the irrigated area by linear interpolation between census years. This was used in calculation of the supplemental indicators of the amount of water applied per acre, as well as the total irrigation water applied (Appendix B). The Irrigation Water Use metric in the Fieldprint® Calculator uses the same equation as the indicator reported here, using field-specific information input by individual users.

The data sources used in the calculation of this indicator are compiled based on USDA Census of Agriculture methodology and are generally robust. However, they rely on farmer self-reporting of both the amount of water applied and the non-irrigated yield estimate. These values are generally known with less certainty. Thus, even though the algorithm to calculate the indicator is relatively simple, there is a moderate level of uncertainty associated with this indicator.

Annual rainfall and groundwater resources in a region will influence grower decisions on irrigation; in turn, these decisions have environmental impacts not captured in the indicator calculation. We currently do not capture the water use by crops nor the return of irrigation water back to the watershed or aquifer. For example, the source of water for irrigation may range from annually replenished streams to stressed aquifers with very slow recharge rates. In areas of water limitation, irrigation water use must be compared against overall water resource limitations to understand water sustainability issues for that region. While characterizing the geographic variability and long-term sustainability of irrigation in different regions of the country is important, it is beyond the scope of a national trends assessment.

Energy Use Indicator

The Energy Use indicator was developed to provide a consistent method for evaluating the efficiency of energy used in a farm operation. This indicator serves as an important set of inputs to the Greenhouse Gas Emissions indicator, described below, as well as a useful measure tied to resource efficiency and profitability of a farm operation. The boundaries defined for the Energy Use indicator are: beginning at pre-planting, including all farm activities for the cultivation of the crop through the growing season and ending at the first point of sale or when transferred to a processing facility. The primary indicator is represented in units of energy use (British thermal units, or BTU) per unit of crop production. We also calculate and present the energy use per acre and total energy use by crop in Appendix B.

The indicator includes the major energy-intensive areas of on-farm crop production. It includes direct energy use from operation of farm equipment, pumping irrigation water, and crop drying, accounting for the fuel type used (diesel, electricity, gasoline, natural gas, or liquefied petroleum gas), and also indirect energy use from fertilizer production and crop protectant production. Our analysis does not quantify the energy associated with manufacturing farm equipment, fuel used on farm, or structures such as grain bins, buildings, etc. To the extent data are available, trends in the energy requirement for the manufacture of fertilizers and crop protectants are included. An example of these efficiency changes is the significant reduction in the amount of natural gas it takes to produce nitrogen fertilizer [45].

The Energy Use metric in the Fieldprint® Calculator shares the same boundaries of calculation as the national level indicator. The metric is field specific and relies on user input to determine the direct energy, and combines user inputs on chemical and fertilizer applications with the data sources mentioned below to calculate the indirect energy components.

The primary data source for calculating this indicator at the national level is the USDA Agricultural Resources Management Survey (ARMS) [46], which captures many on-farm practices including tillage and number of applications of crop protectants and fertilizer. These data are not available for all of the crops considered in this report, so for some crops, assumptions and alternate data sources were necessary. Additional data were acquired from USDA Agricultural Chemical Usage reports [47] and parameter datasets used in the Greenhouse Gas Regulated Emissions and Energy Use in Transportation (GREET 1.8d) model [48]. All energy requirements are converted to BTU for comparison purposes. GHG emissions and embedded energy values for pesticides are taken from Audsley et al. [49]. The approach used here follows the same methodology as in the previous report [13], applying updated data from more recent ARMS surveys when available.

The indicator relies on a range of best available data sources, some of which are available only in multi-year increments, and thus some uncertainty for any given year of indicator calculation is introduced by the need to linearly interpolate between available data years. The algorithm to calculate this indicator is complex but transparent. Thus, while uncertainty from the data is moderate, the ability to interpret national-level trends is high.

Irrigation Energy

Irrigation energy requirement is calculated based on standard engineering methodologies for a bottom-up estimate based on national-level data in the ARMs survey, the Farm and Ranch Irrigation Survey (FRIS), and the Agricultural Census. These reports provided data on the average operating pressure (based on share of irrigated fields using sprinkler/pressure and gravity systems) and average lift of water (based on share of irrigated fields using well water and surface water, and the average depth to wells) required by irrigation pumps, as well as the amount of water applied. This information is used to calculate a national average estimate for energy required for pumping water for irrigation for each crop.

Equipment Operation Energy

One major factor determining equipment energy use is the method of tillage for a crop; for this, data from the ARMS surveys was supplemented with national-level data from the Conservation Technology Information Center (CTIC) [50] on tillage and residue management. Energy and carbon dioxide (CO_2) emissions levels by crop by tillage system (no-till, ridge-till, mulch till, and conservation till) are estimated from West and Marland [25]. For crops where this study does not provide specific data, either a similar crop or corn was frequently chosen as the marker tillage energy crop, as corn is common to the USDA NRCS energy calculator for all states [51], and it is also well defined for all tillage systems in West and Marland [25]. Crop-specific assumptions were made for:

- Barley: Tillage energy for barley was based on that for wheat.
- Cotton: Assumed tillage energy requirement is the same as that for corn.
- Rice: USDA estimates for fuel consumption for rice and corn were used to develop an index value that was then used to adjust the corn tillage energy contribution. This resulted in a national average for a conventional tillage program for rice that is 54 percent that of corn.
- Sugar beets: Tillage energy was based on that for corn, and we assumed 100 percent of conventional tillage throughout the study period.

The portion of planted acreage using each tillage system comes from ARMS and CTIC and is available for all crops, with the exception of potatoes, which was assumed to have a constant share of acreage in each tillage system over time.

Fuel use by on-farm equipment is available from ARMS for most crops. Fuel efficiency for equipment used on farm is assumed to be constant over time. While it is likely that fuel efficiency has increased, at a national average level, data on such changes over time are not readily available. Thus this analysis may underestimate improvement in efficiency associated with equipment technology.

Fuel use data are not available through ARMS for potatoes; therefore, placeholder values were used based on a University of Idaho study of production costs [52]:

- Fuel for fertilizer applications and aerial sprays – 1.7 gallons of diesel/planted acre/year
- Fuel for soil fumigation operations at 4.78 gallons of diesel/acre corrected by the percent of acres fumigated in each year
- Fuel use for other tractor operations (such as land prep, tillage, harvest) set at a value of 27.23 gallons of diesel/acre/year and 3.19 gallons of gasoline/acre/year
- Hauling was calculated at 0.07 gallons of diesel/cwt.

Energy associated with manure application is calculated using ARMS data on application rates, number of applications, and manure species to estimate the loading and application energy used for all crops. Using engineering data on fuel use for tractor loading and spreading, a factor of 0.0862 gallons of diesel fuel per ton of manure (wet basis) applied is used to estimate the loading and application energy for manure.

Post-Harvest Treatment Energy Use

The scope of the indicator considers energy used up to the first point of sale. This can vary considerably by crop, due to differences in storage or treatment of the harvest. Grain drying energy use was drawn from USDA reports and

Crop	Points of moisture removed	One-way distance transported – miles
BARLEY	1.4	45
CORN (GRAIN)	2.9	30
CORN (SILAGE)	0	3
PEANUTS	12.5	45
RICE	5.0	30
SOYBEANS	1.4	45
SUGAR BEETS	0	15
WHEAT	1.4	45

Table 1.2: Estimated drying and transportation requirements based on expert assessments.

extension resources [53]. The amount of moisture removed from grain and cotton was considered constant over time, as were the efficiencies of drying equipment.

Distances from farm to the first point of sale were estimated and are provided in the table below. These were used in conjunction with EPA data on fuel consumption of heavy trucks to develop the transportation estimate (6.5 miles per gallon of diesel) [54]. Estimated distances are provided in Table 1.2, based on expert judgment after consultation with commodity group representatives and experts. This transportation energy is held constant over time due to the lack of time series-specific data.

Cotton is handled differently from grains; values for drying and transport are provided by Cotton Incorporated. Cotton is assumed to be moved an average of 10.1 miles from the field to the gin and lint warehouse. An estimated 0.52 gallons of diesel are needed to transport 1,000 pounds of lint to the gin, and the energy to dry the lint is 739 BTU per pound from propane and 239 BTU from electricity; this assumes a "normal" drying level for all cotton (as compared to extremely dry or wet). The factors are held constant per unit of production basis over the study period.

Peanuts are also a unique case; here we assume that peanuts must be dried to 10 percent moisture content, and are harvested from the field at 22.5 percent [55]. Peanuts are typically dried in the field to the extent possible, and this can vary considerably by producer as well as region.

Potatoes also are handled differently from grains; the first point of sale may occur on the farm or off the farm, depending on the sales arrangement a grower has with the buyer. In addition, much of the fall potato crop is stored on farm after harvest. This is to achieve yearlong supply for the fresh market and to make efficient use of capital investment in processing facilities. Energy is used to cool the storage facility and provide for air circulation to preserve quality. Time in storage is highly variable, from a few weeks to 10 months. Here, we assume storage of 120 days on farm and no transportation energy requirement. In storage, energy is required for ventilation and cooling. Energy for ventilation ranges from 3–13 kWh/1,000cwt./day, which represents a significant fraction (3–10 percent) of total energy use for potato production. Energy for cooling varies greatly with the ambient temperature. The efficiency of mechanical refrigeration systems also varies greatly with the age of the system. A substantial proportion of the cooling is also driven by evaporation—particularly at the beginning of the storage period.

Chemical Fertilizer

USDA's Economic Research Service (ERS) provides national-level data on the acreage and percentage of acreage of major crops that use chemical fertilizers, as well as the rate of fertilizer application [56]. Years without data on application rates from USDA were estimated by linear interpolation between years on the basis of rate (pounds/acre). By multiplying the percentage of acres fertilized by the application rate, we calculate fertilizer amounts applied per planted acre. Dividing by USDA's yield data then results in the amount of fertilizer applied per unit of production. Fertilizer application rates for nitrogen, phosphorous (P_2O_5) and potassium (K_2O) are multiplied by energy conversion factors provided in the GREET 1.8d model [48]; these factors include embedded energy and transport energy for fertilizer. Values used for all crops are as follows:

- BTU per pound N: 23,646
- BTU per pound P_2O_5: 5,945
- BTU per pound K_2O: 3,722

For soybeans, supplementation nitrogen fertilizer is generally not required. However, diammonium phosphate (DAP) is one of the most common forms of phosphorus fertilizer, and it contains nitrogen. Thus, nitrogen fertilizer is included in soybean calculations as a result of DAP applications.

Fertilizer data for barley were available only from the ARMS survey in 2011. Consequently, for other years the fertilizer application for barley was scaled to the trends in fertilizer applications for wheat.

Crop Protectants

Data on the quantity of agricultural chemicals used by crop type are available from USDA's ARMS survey and its Agricultural Chemical Usage reports [56]. USDA ARMS data utilize four categories for pesticides: herbicides, insecticides, fungicides, and "all other." All data are reported as total pounds of active ingredient applied. Values for embedded energy in pesticides are taken from Audsley [49], which provides factors for energy and GHG emissions for the three named USDA pesticide categories (herbicides, insecticides, and fungicides). Fumigants, plant growth regulators, defoliants, and other pesticide GHG and energy values are not available in the study; given their chemical nature, these products are included in the herbicide category. For each category, the average energy per unit of active ingredient was multiplied by application rates.

Product average values used for all crops/all years were as follows, as derived from Audsley [49]:

- BTU per pound herbicides: 113,715
- BTU per pound insecticides: 92,175
- BTU per pound fungicides: 74,377
- BTU per pound for products in USDA's "all other" category: 113,715

Seed

Energy in seed used for planting is estimated as a proportion of the crop harvest that would be needed to provide seed for establishment. The yield of crops grown for seed is generally lower than the crop yields for grain production and also require more fertilizer and chemical input; thus, two factors are held constant across all crops: the seed production yield factor (0.66) and the seed production energy intensity factor (1.5). In effect, the factors imply that seed yields are 66 percent that of production for the general market and that input usage (fertilizer, tillage, etc.) is 150 percent that of commercial production. No official source exists for these seed factors; they were derived through discussions with industry experts. The seed factors were also developed to be a conservative (high) estimate of the likely energy used to produce seed. Seed usually accounts for less than 2 or 3 percent of the total energy to produce the crop.

Grain Yield	150	Bushels per Acre
Seed Yield Factor	66	Percent of Grain
Seed Yield	99	Bushels per Acre
Seed Input Intensity Factor	150	Percent
Seed Use Rate	25,895	Kernels
Seed Conversion	80,000	Kernels per Bushel
Seed Energy Share	0.49	Percent

Table 1.3: Example of seed energy calculation for corn.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator shares the same boundaries of calculations as the Energy Use indicator, and utilizes much of the same data. In addition to translating the energy use into emissions based on fuel type, the U.S. EPA inventory of emissions [28] is used to provide estimates of methane and nitrous oxide emissions. The Greenhouse Gas Emissions indicator does not account for soil carbon stocks or fluxes, as those are not currently included in the corresponding field-scale metric. We consider national-level trends in soil carbon in Part Two of this report, and are currently considering revisions to the field-scale metric to allow for incorporation of soil carbon in the total GHG balance.

The data sources used are similar to the Energy Use indicator but transformed using further assumptions regarding fuel type and supplemented with data from the U.S. EPA inventory. The inventory values used are for nitrous oxide from soils, methane from flooded rice fields, and residue burning. These are calculated with complex models and come with an additional level of uncertainty. Thus the uncertainty for the Greenhouse Gas Emissions indicator should be considered to be slightly higher than that for the Energy Use indicator.

Emissions from Energy Use

Energy use, as described in detail in the previous section, is converted to emissions by considering the source of energy (fuel type), and the resulting emissions are reported as pounds of carbon dioxide (CO_2) equivalent (CO_2e). CO_2e is a common measure for assessing total GHG emissions that accounts for the relative strength of the Global Warming Potential (GWP) of different GHGs. Thus, CO_2e provides a method to combine emissions of CO_2 with emissions of methane and nitrous oxide in a common unit for comparison. A factor of 22.3 pounds CO_2 emitted per gallon of diesel combusted was used.

The carbon emissions due to equipment operation for alternative tillage systems were taken from West and Marland [25] (Table 1.4).

The three tillage systems are consistent with the definitions used by the CTIC and USDA's ARMS data: conventional till, reduced till, and no-till. CTIC provides data over time of the percentage of each crop under the different tillage practices. The CTIC values are provided for corn, soybeans, wheat, and cotton [50]. USDA ARMS data are used for rice; conventional till is assumed for potatoes with the assumption of little or no change in tillage practices (and thus tillage energy and emissions) for potatoes over time [52]. Conventional till uses the most energy for machinery, and hence produces the largest carbon emissions of the three practices. No-till uses the least amount of energy, and hence produces the least amount of carbon emissions. For crops not included explicitly in West and Marland [25], the same adjustments as were made for Energy Use, described above, were used.

The analysis in this report assumes that these emissions factors have not changed over time. According to researchers at the Nebraska Tractor Test Laboratory [57], the focus of agricultural engine research and development has been to reduce emissions from farm equipment. While the specific impact of this assumption is not known, the likely impact of improvements in energy efficiency and associated emissions from farm equipment over time would be reduced emissions. That trend is not captured in the results reported here. Changes in the emissions from machinery therefore come only from changing tillage practices over time. Efficiency gains due to increased adoption of no-till and reduced-till practices are captured using the CTIC [50] and ARMS [46] data for the share of each crop under each tillage system.

Emissions from the pumping and distribution of irrigation water are estimated from the energy calculation. Given the prevalence of electric pumps used in irrigation, the improvements in emissions from the national grid are taken into consideration with regard to irrigation. The emissions from grain drying, crop storage (potatoes), and transport are likewise calculated in a consistent manner with the energy used for these activities. The amounts of fuel energy combusted and electricity consumed are used to estimate GHG emissions. Propane is assumed as the fuel used for drying, while diesel is assumed as the fuel used for transport. Electricity values are assumed as average emissions from the national grid including improvements in emissions over time.

Carbon Emissions from Machinery Operation	Corn	Soybeans	Wheat
Conventional (kg carbon per hectare)	72.02	67.45	67.45
Reduced Tillage (kg carbon per hectare)	45.27	40.70	40.70
No-Till (kg carbon per hectare)	23.26	23.26	23.26

Table 1.4: Emissions from machinery operations from West and Marland (2002) [25].

Emissions Embedded in Chemicals and Fertilizers Applied

USDA's Agricultural Chemical Usage report provided data on chemical usage and fertilizer use for all crops [47]. These product application rates were interpolated between reference years on a rate-per-acre basis. Emissions factors for product-embodied CO_2 were taken from the GREET model version 1.8d [48] for fertilizer and from Audsley [49] for crop protection products. These emission factors were adjusted to account for efficiency changes over time for natural gas to ammonia fertilizer conversion (for nitrogen fertilizer), and for emissions changes on the electric grid over time (for crop protection products). The electric grid correction factor was chosen for crop protection products because of the high relative importance of electric power in their production [49].

The embedded GHGs in seed is estimated in the same manner as for energy—as a fraction of the total GHGs to produce the crop, using the same adjustment factors described in the previous section.

Nitrous Oxide Emissions from Soils

Nitrous oxide is a GHG with a global warming potential (GWP) of 296 times that of CO_2 [58]. Nitrous oxide released from soil microbial activity in association with fertilizer nitrogen application is an important source of emissions. However, the range of estimates for nitrous oxide as a percent of nitrogen applied is very wide depending on the source of nitrogen, the method of application, and the soil conditions at the time of application. A literature review by Snyder et al. [59] found that nitrous oxide emissions as a percent of nitrogen applied can range from near zero to nearly 20 percent of applied nitrogen lost as nitrous oxide. Bouwman et al. [60] report a global mean of 0.9 percent of nitrogen from fertilizer is released from soil as nitrous oxide, while a recent paper by Shcherbak et al. [61] found that while the nitrogen fertilizer application rate remains the best single indicator of nitrous oxide emissions, it is still imprecise and does not follow linear trends.

For the purposes of this analysis we use a single factor, consistent with a Tier 1 approach as recommended by the Intergovernmental Panel on Climate Change (IPCC) [58], to estimate nitrous oxide emissions from fertilizer applications at a national average scale. The applied nitrogen from synthetic fertilizer and manure is multiplied by 1.4 percent to estimate the nitrogen that is emitted as nitrous oxide. This 1.4 percent factor accounts for emissions from all sources, both direct and indirect. The IPCC assumes that 1 percent of applied nitrogen fertilizer (uncertainty range of 0.3–3.0 percent) is lost from direct emissions of nitrous oxide at the field level due to nitrification/denitrification. This assumption is based on scientific publications that report losses for specific crops and cropping systems [62]. Indirect nitrous oxide emissions result from denitrification of volatilized ammonia (NH_3) deposited elsewhere, from nitrate (NO_3) lost to leaching and runoff as the nitrogen cascades through other ecosystems after leaving the field. The IPCC assessment protocol assumes that volatilization losses represent 10 percent of applied nitrogen, and that nitrous oxide-nitrogen emissions for these losses are 1 percent of this amount; leaching losses are assumed to be 30 percent of applied nitrogen, and nitrous oxide-nitrogen emissions are 0.75 percent of that amount [62]. Therefore, the IPCC default value for total direct and indirect nitrous oxide emissions represents about 1.4 percent of the applied nitrogen from fertilizer.

While sophisticated models exist to more closely estimate nitrous oxide emissions on a field scale [28], these models do not provide estimates over time that are crop specific. Rather, they simulate multi-year cropping systems over thousands of fields and use complex aggregation and weighting to derive a total estimate at the national level. The U.S. EPA inventory modeling is discussed in more detail in Part Two of this report. Field to Market continues to explore emissions factors for nitrous oxide that would provide appropriate variation based on nutrient management and cropping system, but in the current report for a national average, the 1.4 percent factor is applied. We recognize that this is likely an overestimate of nitrogen losses from well-managed, high-yielding systems.

Data on mean annual nitrogen applied from fertilizer and manure application were taken from USDA's ARMS data [46], which include tons applied and manure source by crop over time. Data are not reported for all years; therefore, non-reported years are interpolated on a rate-per-acre basis and held constant prior to the data beginning and after the last data point. Management factors such as split application on nitrogen as well as application method and timing can have significant impacts on the ultimate emissions level from applied nitrogen. The approach we have taken does not capture these differences or their potential to have changed over time. This approach also does not account for background soil nitrous oxide emissions that occur in cropping systems without nitrogen fertilizer applications (e.g., soybeans and other nitrogen-fixing leguminous crops).

To convert the emissions from applied nitrogen into CO_2e, we have accounted for the ratio of the molecular weight of nitrous oxide to nitrogen (44/28) and the CO_2e factor for nitrous oxide (296). Using these factors, 100 pounds of applied nitrogen results in emissions of 651 pounds CO_2e. Example: Emissions from 100 pounds applied nitrogen = 100 X 1.4 percent X (44/28) X 296 = 651 pounds CO_2e.

Emissions from Field Burning and Residue Removal

Emissions from field burning of surface residue are a relatively small share of total emissions from agricultural production; however, in cases where residue is burnt, the impact can be significant. Field-burning emissions are not calculated for potatoes, sugar beets, or peanuts, which typically have no surface residue that would warrant burning. Additionally, little or no field burning is performed for soybeans or cotton. Levels of residue burning are taken directly from the EPA reporting of GHGs from agriculture [28]. The quantity of surface residue available to be burned is calculated as a proportion of the crops' yield; crop-specific factors are available for every crop. The final calculation determines the amount of methane and nitrous oxide released into the atmosphere. The release of CO_2 is not counted, as it is expected to be released over time via decomposition and is thus considered part of the natural annual uptake and emission of CO_2 from plant growth rather than an anthropogenic emission. Among the crops in our analysis, burning of rice residue is the most prevalent, with 10 percent of acres burnt [28]. Emissions from residue burning account for about 0.5 percent of total emissions for rice.

Among the crops in this analysis, wheat is the only crop for which a measurable share of the acres has residue removed following the primary crop harvest. Removing the residue from an annual crop field reduces the GHG impact by reducing the CO_2 emissions from residue breakdown on the field. A value of 0.21 pound nitrogen from residue per bushel of grain harvested times the amount of acres harvested for straw of wheat harvested is thus subtracted from the indicator. According to USDA ERS [35], straw is removed from 13 percent of all wheat acres with an assumed 50 percent of the surface residue being removed. At the national level, wheat straw removal reduces GHG emissions for the crop by between 0.5 and 0.75 percent. The same assumed fractions were also used to calculate residue burning and removal for barley.

Methane Emissions from Flooded Rice

Methane emissions are the result of anaerobic conditions that occur in fields that need to be flooded for continuous periods of time during the growing season in order to produce a rice crop. Emissions for rice are based on the levels reported in the U.S. EPA's annual inventory of GHG emissions [28]. A recent change in methodology for the U.S. EPA report resulted in a significant change in nationally estimated methane emissions from rice production. In the latest report [28], a detailed process-based model was applied to simulate rice production on mineral soils, replacing a simpler accounting approach. While the trend of emissions remains similar to that reported in 2012, the absolute amount of GHG emissions from rice is higher in the 2016 report due to the revision in the U.S. EPA methodology.

U.S. inventory data were scaled to a per-planted-acre basis for the period 1990 through 2010. Years prior to 1990 were set to the 1990 level, while years after 2010 were held constant at the 2010 level, again on a per-planted-acre basis. Consistent with U.S. EPA's reporting of the data, methane emissions have trended lower over time on both a per-acre and per-unit-of-production basis. It should be noted that methane emissions from other crops due to flood irrigation are considered to be insignificant due to the relatively limited number of acres flooded and the short duration of flooding.

Methodology Summary

The methodology described here has been developed and refined since the initial 2009 report. As additional data and new methods are developed, we will continue to provide updates to these environmental indicators. The ability to continue and improve on these analyses is dependent on the availability of the public data sources, surveys, and modeling upon which the analyses heavily rely. Public, national-level datasets provide a transparent, accessible, and fundamental means of understanding sustainability trends.

We have included here some discussion of the sources of uncertainty within each indicator, to provide some context as to how these trends can be discussed. All methodologies to assess complex systems at a large, aggregate scale will introduce some uncertainty due to the need for data collection, sampling, aggregation, analysis, and, in some cases, simulation modeling. So long as the methodology is robust, transparent, and consistent, we can have a high level of confidence that the trends over time reflect real change on the ground.

Furthermore, while many datasets are currently available for the crops evaluated, the expansion of these methods to other crops would be limited by data availability, including ARMS data for crops with smaller acreages. In addition, access to data over time on the efficiency of farm equipment, including use of alternative and renewable energy sources, would greatly improve the accuracy of trends reported for energy use and GHG emissions. Where necessary, we have reached out to commodity and industry groups to gather insights and data for use in refining some assumptions, in particular regarding prevalence of certain management practices that impact energy use and GHG emissions.

The results of these indicators are presented in the next section; while in many instances these are similar to trends in the 2012 report with several additional years of data, there are two important data points for which the entire historical series is recalculated. These are the data series from USDA that are dependent on simulation modeling—soil erosion rates and rice methane emissions—for which changes in the USDA methods require re-simulation of the full historical series. Many of the data sources used in those calculations, as well as directly in the indicator calculations here, are available with a time lag. For example, the extensive NRI survey results on tillage, fertilizer, and other farm management practices require several years of analysis at USDA before being publicly released. While this is necessary for quality control and confidence in aggregate data estimates, it means that different components of the indicators calculated here represent various different points in time for U.S. agriculture. Therefore, our focus is on the long-term trends rather than any particular year.

ENVIRONMENTAL INDICATORS RESULTS

Overview

Here we present the results of the national environmental indicators described in the previous section. The five indicators presented are accompanied by information on total production and area, as well as evaluations of the rate of change and how the trends have evolved over time. Additional information is available in Appendix B to assist with interpreting the overall resource use and per-acre efficiency of the indicators presented in this section. While the total environmental impact and resource use are important to understanding overall trends and drivers, by expressing the use of key resources—land, water, and energy—in terms of units of production, we focus here on trends related to efficiency. Maintaining and improving the efficiency of resource use are the ways producers can seek to remain sustainable even as demands for increased production must be met.

Four of the indicators here explicitly account for the efficiency of resource use per unit of crop yield:

- Land Use Indicator: A measure of the efficient use of land (acres per unit of production)
- Irrigation Water Use Indicator: A measure of the efficient use of irrigation water (acre-inches of water applied per additional unit of production)
- Energy Use Indicator: A measure of the efficient use of energy (British thermal units (BTU) per unit of production)
- Greenhouse Gas Emissions Indicator: A measure of emissions associated with production (pounds of carbon dioxide equivalent (CO_2e) per unit of production)

The fifth indicator is Soil Conservation, which is expressed per acre. Soil is considered somewhat different from other resources in commodity crop production due to the very long time required for regeneration; thus, reductions in loss of soil per acre are key to sustaining productivity. Methods and data sources for calculating the national indicators over the 36-year period of analysis are detailed in the previous section.

In this section, results are expressed graphically in three forms:

- A summary spidergram shows the change in the overall national efficiency of the five primary indicators. This is displayed for four separate five-year averages spanning the full period of analysis (1981–1985, 1991–1995, 2001–2005, and 2011–2015). In order to evaluate relative changes across multiple indicators with differing units of measure, each indicator is indexed so that values for year 2000 are set equal to 1. Therefore, a 0.1 unit change in the index value of an indicator is equal to a 10 percent change relative to the value of that indicator in year 2000. Trends that demonstrate movement toward the center of the spidergram represent an improvement in efficiency over time. Note that calculation of change in these fixed intervals relies on linear interpolation of certain data sources that are not available on an annual basis. More detail on which data sources are interpolated and the available data years is provided in the Methodology section.
- Summary bar charts over the 36-year study period and for four equal eight-year time periods give an indication of the overall change as well as how the direction of the trends has changed over time. These compare specific points in time to calculate the percentage change between the first year and the last year of the identified period. Note that calculation of change in these fixed intervals relies on linear interpolation of certain data sources that are not available on an annual basis. More detail on which data sources are interpolated and the available data years is provided in the Methodology section.
- Individual line graphs for the five indicators are also presented to provide additional resolution regarding changes over time. These are also used to produce linear trend lines to further illustrate the long-term trend. The presence of the trend line does not imply that the relationship is a best fit relationship model or a statistically significant trend.

PART ONE: ENVIRONMENTAL INDICATORS

The trends described below are the result of many different environmental, social, and policy drivers and represent innumerable individual producer decisions regarding management. Our intention is to provide an overview of how these forces and decisions, in aggregate, have influenced the resource use efficiency of U.S. commodity agriculture over the long term. Where the data that were used in the indicator calculations can explain changes over time, some interpretation is provided. However, we do not attempt a thorough, geographically specific interpretation that would be needed to fully understand some of these trends or provide a robust statistical assessment. Thus, while linear trend lines are provided to illustrate whether there is a consistent directional change over time, this should not be considered a measure of the statistical significance of trends.

Environmental Indicator Results by Crop

In order to provide context for evaluating the environmental indicators, we present the total production, crop yield, and planted area in Table 1.5. The percentage change in 2015 from the 1980 initial value, based on linear trend, shows that yield increased for all crops, with the greatest yield improvements (over 60 percent) for corn for grain, potatoes, rice, and soybeans. In contrast, the planted acreage for each crop varied, with reductions in planted acreage of barley, corn for silage, soybeans, and wheat across the study period. These two points of information drive the observed changes in production, which declined for barley and wheat but increased for all other crops. Notably, both corn for grain and soybeans had production increases at or near 120 percent, with production in 2015 more than double that of 36 years prior. Overall, for the 10 crops considered here, planted area declined by 8 percent, or roughly 20 million acres, over the study period.

Table 1.6 provides an overview of the linear trend over the full analysis period for the five indicators and illustrates that overall, the key environmental indicators improved. The one exception is in the trend of soil erosion for peanuts; erosion for peanut production in 2015 was higher than in 1980. These overall trends are explored in more detail below for each of the crops individually.

Crop	Total Production	Yield per Acre	Planted Area
BARLEY	-72	34	-81
CORN (GRAIN)	119	61	33
CORN (SILAGE)	24	58	-23
COTTON	35	42	2
PEANUTS	41	74	-17
POTATOES	28	65	1
RICE	61	62	31
SOYBEANS	120	63	20
SUGAR BEETS	41	46	0
WHEAT	-17	29	-35

Table 1.5: Percentage change in total production, yield, and planted area for each crop in 2015 compared to 1980 based on linear trend line. Positive values indicate increases over time.

	Land Use *Acres per unit production*	Soil Conservation *Tons per acre*	Irrigation Water Use *Acre-inch of water per unit production*	Energy Use *BTU per unit production*	Greenhouse Gas Emissions *CO_2e per unit production*
BARLEY	31	43	59	22	11
CORN (GRAIN)	41	58	46	41	31
CORN (SILAGE)	37	58	10	42	28
COTTON	31	44	82	38	30
PEANUTS	40	-64	66	28	30
POTATOES	25	25	43	20	28
RICE	39	72	50	38	38
SOYBEANS	40	40	32	35	38
SUGAR BEETS	28	3	47	33	32
WHEAT	22	28	26	22	9

Table 1.6: Percentage improvement in 2015 compared to 1980 for selected indicators based on a linear trend line fitted to each indicator. Positive values indicate an improvement (reduction in resource use per unit production or acre) in 2015 when compared to 1980.

BARLEY

Barley is a new crop in the Field to Market program and thus was not included in the 2012 indicator report. While total production and area planted of barley declined over the 36-year period, the environmental indicators show improvement in the resource use per unit of production, in particular for Soil Conservation and Irrigation Water Use. Figure 1.1 displays five-year averages for four evenly spaced (but not continuous) time periods. The most recent five-year period has the lowest values, and therefore the lowest environmental impact, for all five indicators. This has not been a continuous change, as the results for Energy Use and Greenhouse Gas Emissions are lower in the first period (1981–1985) than in the middle two periods.

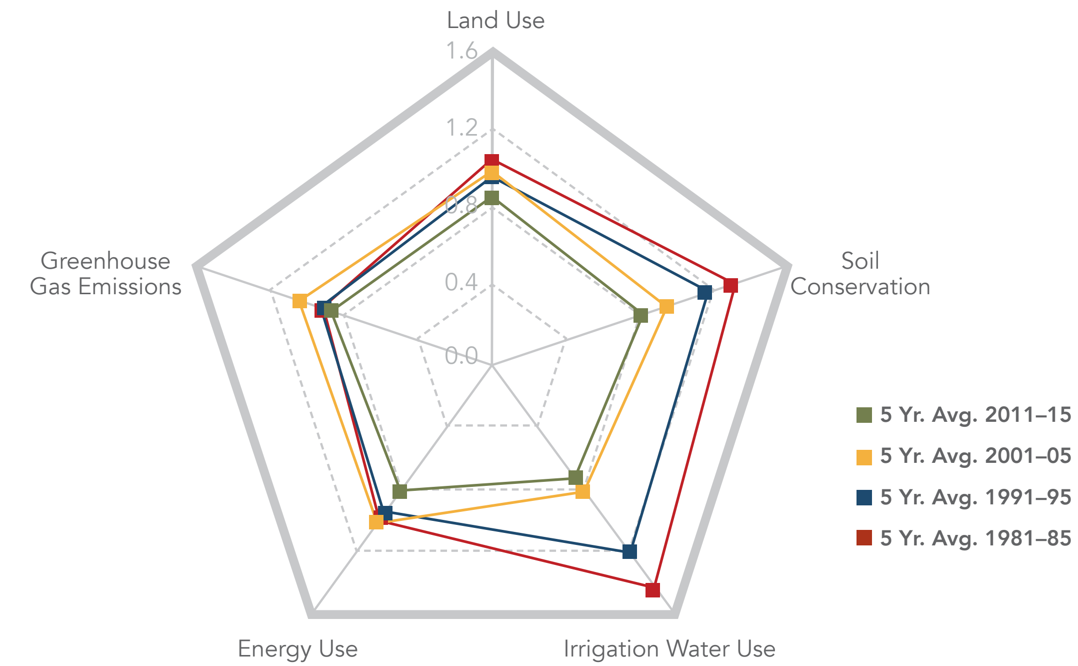


Figure 1.1. Indicators of resource use impacts to produce barley.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.018	Planted acres per bushel
Soil Conservation	6.1	Tons per acre
Irrigation Water Use	0.437	Acre-in per bushel
Energy Use	70,679	BTU per bushel
Greenhouse Gas Emissions	16.2	Pounds CO_2e per bushel

** Five year average 1996–2000*

The total percentage change over the full time period indicates improvements have been greatest in Irrigation Water Use and Soil Conservation (Figure 1.2) when comparing the actual values in 2015 with those from 1980.

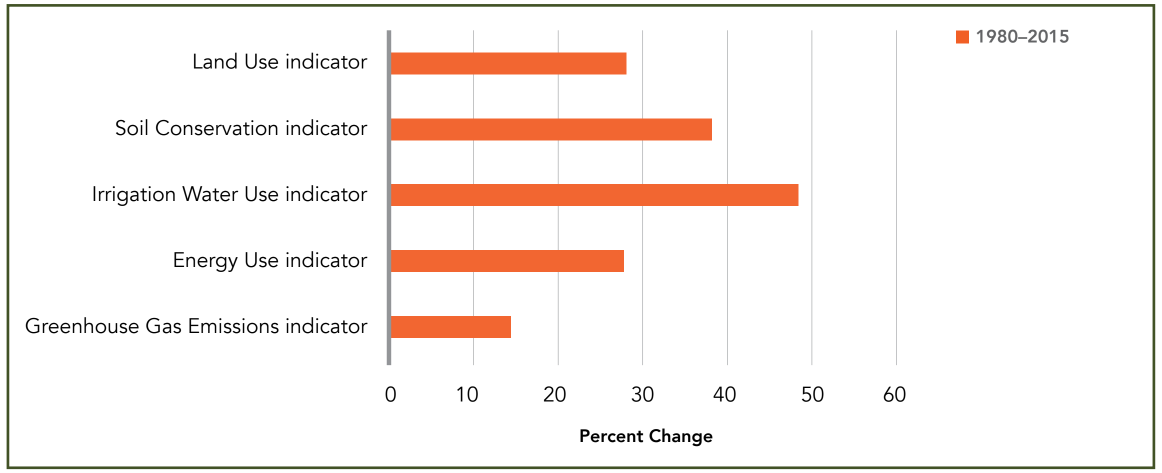


Figure 1.2. Total percentage improvement in 2015 compared to 1980 for the five indicators for barley.

When the percentage change is calculated for four equal periods of eight years, there is a clear trend of some negative environmental trends between 1980 and 1988. 1988 was an anomalously low-yield year for barley due to extensive drought that particularly affected the regions of the country where barley is grown. In 1988, national average yields were only 38 bu./acre, compared to nearly 50 bu./acre in both the preceding and following years. That anomaly in turn influences all of the indicators except for soil erosion, and is especially apparent as 1988 is used as one of the core years for the analysis in Figure 1.3. Aside from that anomaly, the percentage change in 2006 as compared to 1998 was also slightly negative for Land Use, Energy Use, and Greenhouse Gas Emissions. All indicators show positive trends of improvement in the most recent periods (i.e., since 2007).

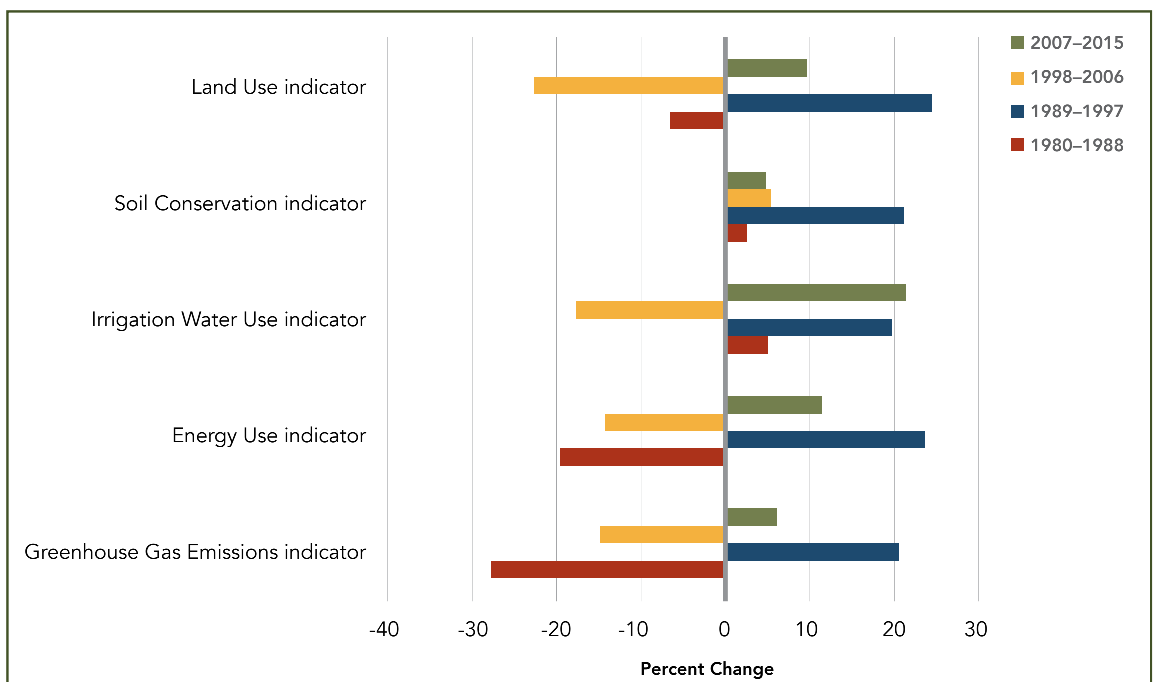


Figure 1.3. Percentage change in four equal periods for the five environmental indicators.

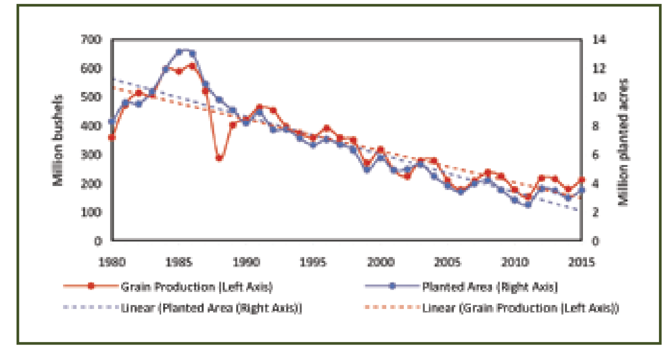


Figure 1.4. Total grain production and planted area for barley.

Total Production and Area

The total production and area of barley declined over the study period, with an increase from 1980 to 1986 followed by a decline to 3.6 million planted acres and 214 million bushels in 2015 (Figure 1.4). Production and planted area have remained steady throughout the last four years of the analysis.

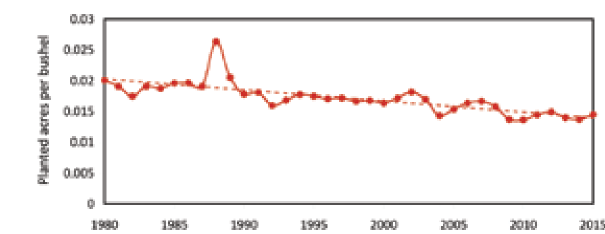


Figure 1.5. Land Use indicator for barley.

Land Use Indicator

The Land Use indicator also declined over the study period, illustrating a steady, although small, increase in crop yield. A low crop yield due to drought in 1988 resulted in a discontinuity in the trend. Other drought years are also evident in reduced production, in particular 2002.

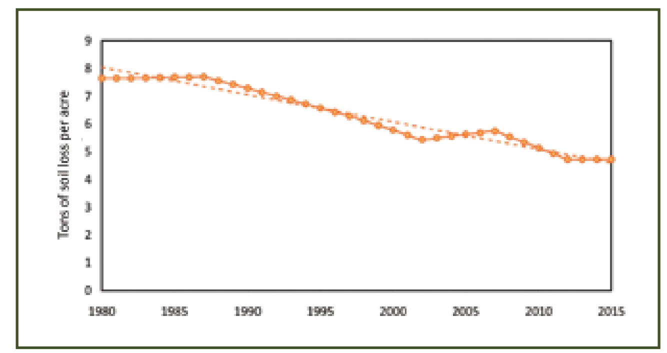


Figure 1.6. Soil Conservation indicator for barley.

Soil Conservation Indicator

The Soil Conservation indicator likewise shows an improving (declining) trend over time, with a slight increase in the 2002–2007 period before resuming the downward trend. The latest year for which soil erosion estimates are available from USDA is 2012, and for all crops we hold the erosion rate constant at the 2012 level through the end of our analysis period (2015). One driver of this reduction in erosion is increased adoption of both reduced and no-till management. While tillage information is not available explicitly for barley, here we assumed tillage trends to be the same as those for wheat. Both reduced tillage and no-tillage have increased by 25 to 30 percent, respectively, displacing conventional tillage, from the early 2000s to the present.

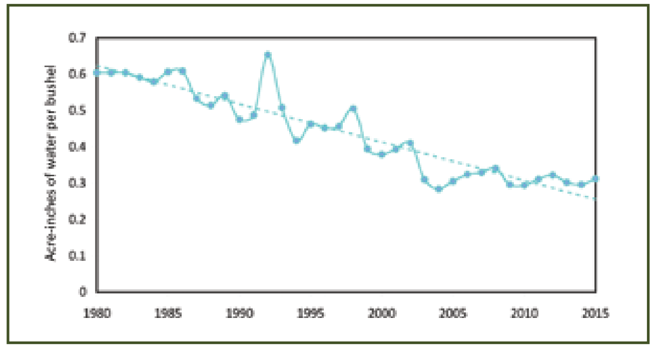


Figure 1.7. Irrigation Water Use indicator for barley.

Irrigation Water Use Indicator

The Irrigation Water Use indicator displays considerable variability, as it responds to changes in both crop yield and crop water requirement and thus is heavily influenced by weather events. Overall the indicator does continue to decline over time, representing greater marginal gains in productivity from irrigation water use but illustrating relatively little directionally consistent change since the early 2000s (Figure 1.7).

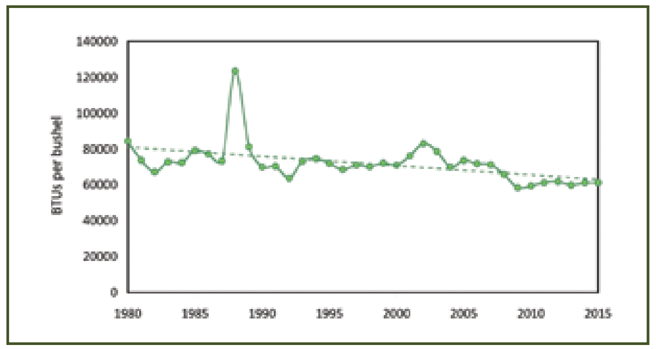


Figure 1.8. Energy Use indicator for barley.

Energy Use Indicator

The Energy Use indicator has a slight decline in energy use per bushel of production over time. The anomalous yield in 1988 is apparent here in a spike in energy use per bushel in that year, driven by changes in tillage as well as other energy use on farms (Figure 1.8). The relatively small improvement over time highlights the critical role that increasing crop yields have on driving the efficiency indicator trends.

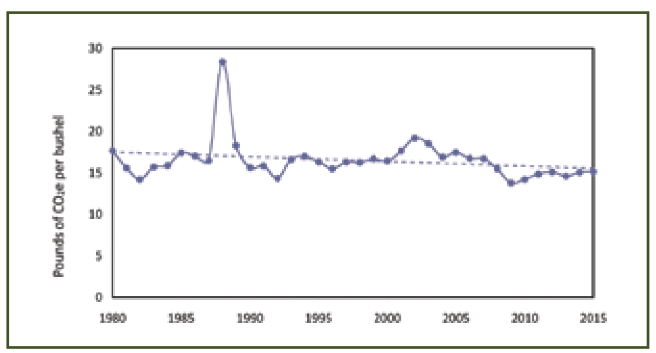


Figure 1.9. Greenhouse Gas Emissions indicator for barley.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator is likewise quite steady throughout the study period, and variation mirrors that observed in the Energy Use indicator. The indicator increased slightly in the early 2000s before declining again, and has been roughly steady over the past five years (Figure 1.9).

PART ONE: ENVIRONMENTAL INDICATORS

CORN FOR GRAIN

Over the study period (1980–2015), the five main indicators of sustainability showed improved trends for U.S. corn for grain production. The most recent five-year period, summarized in Figure 1.10, of 2011–2015, shows continuing improvements in resource impacts for soil erosion compared to the 2001–2005 time period. For the Energy Use and Land Use indicators, the resource impact of corn production has held steady, while slight increases in the Greenhouse Gas Emissions and Irrigation Water Use indicators are observed in this most recent period.

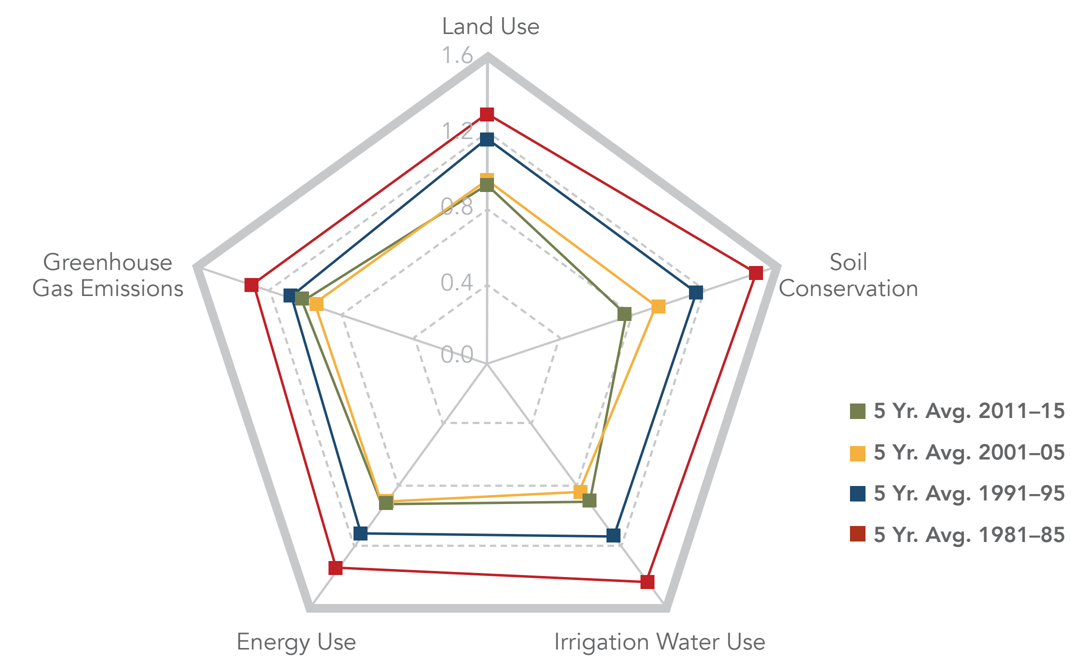


Figure 1.10: Indicators of resource use impacts to produce corn for grain.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.008	Planted acres per bushel
Soil Conservation	4.8	Tons per acre
Irrigation Water Use	0.242	Acre-in per bushel
Energy Use	49,059	BTU per bushel
Greenhouse Gas Emissions	13.211	Pounds CO_2e per bushel

** Five year average 1996–2000*

To further understand the rate of change and the evolution of trends over time, Figures 1.11 and 1.12 present the percentage change over the full period and in four equal eight-year increments.

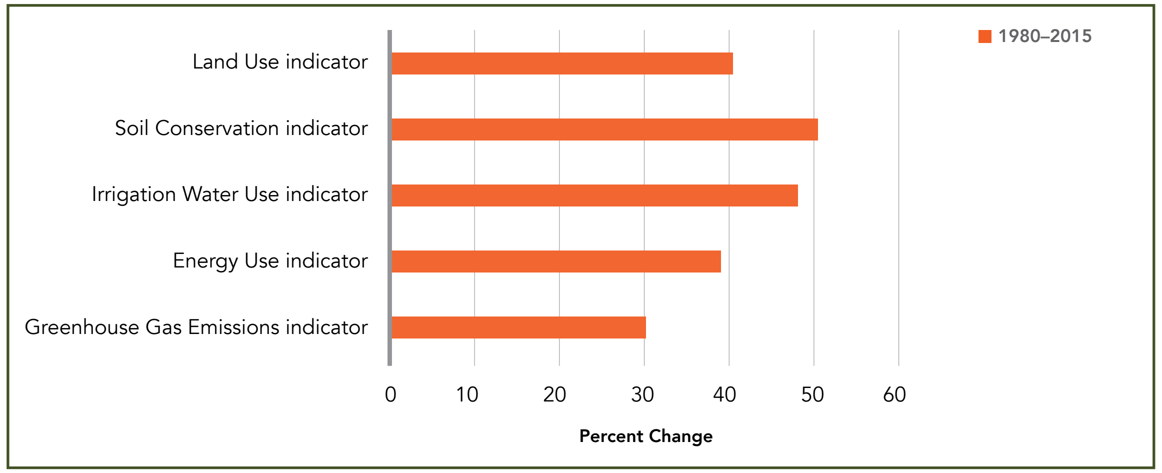


Figure 1.11. Total percentage improvement in 2015 compared to 1980 for the five indicators for corn for grain.

While improvement over time (positive percent change) is seen over the full 36-year period, we can see that when this improvement was realized differs for each indicator (Figure 1.10). The Land Use indicator experienced the greatest improvement in the middle of the time frame, from 1989 to 2006, and has experienced little change since then. For Soil Conservation, improvements from 1980 to 2006 have also largely leveled off in recent years. Large gains in Irrigation Water Use efficiency have reversed in the most recent eight-year period. Energy Use and Greenhouse Gas Emissions, which are closely related indicators, follow a similar pattern, with the greatest improvements achieved from 1989 to 2006, illustrating efficiency improvements driven by yield increases.

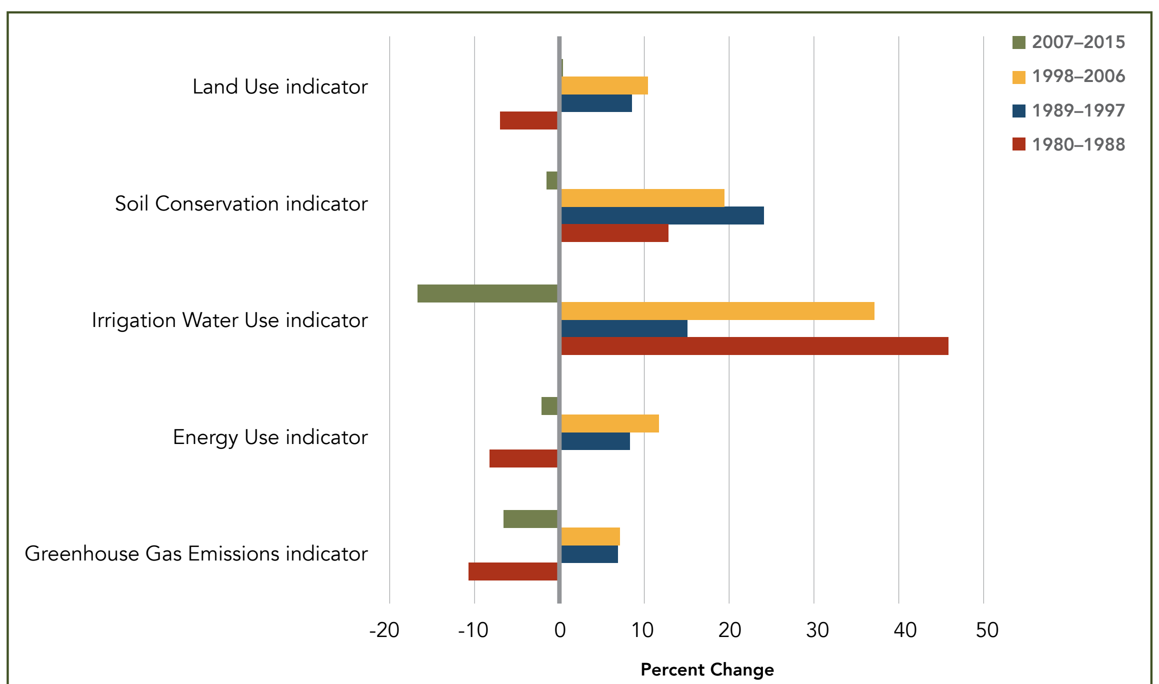


Figure 1.12. Percentage change in four equal periods for the five environmental indicators for corn for grain.

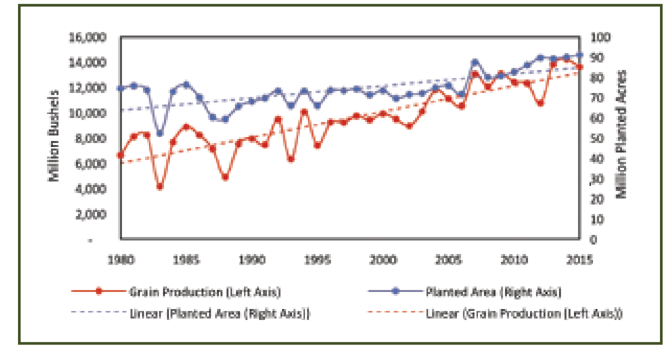


Figure 1.13. Total production and planted area of corn for grain.

Total Production and Area

Total production and planted area for corn for grain increased over the study period (Figure 1.13). Total production of corn increased to 13.6 billion bushels of corn produced in 2015 compared with 6.64 billion bushels in 1980. The increase in production corresponded with a 33 percent increase in total planted acreage. Climate events in 1983, 1988, 1993, and 2012 are particularly apparent in causing low production years for corn.

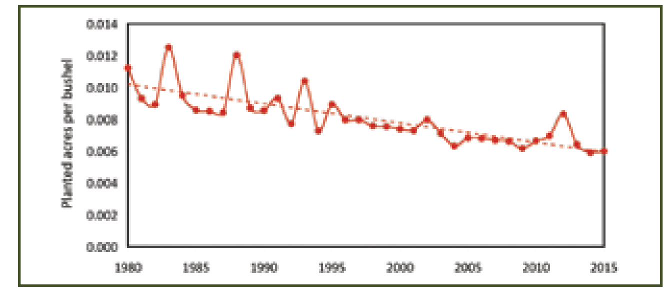


Figure 1.14 Land Use indicator for corn for grain.

Land Use Indicator

While total planted area increased over the study period, the Land Use indicator (planted acres per bushel) improved 41 percent (Figure 1.14). This represents improvements in crop yield over the period, with average yield in 2015 of 166.5 bushels per planted acre, compared to 89.1 bushels per planted acre in 1980.

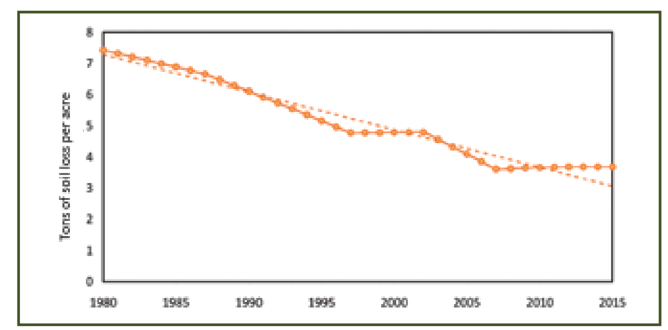


Figure 1.15. Soil Conservation indicator for corn (grain and silage)

Soil Conservation Indicator

The Soil Conservation indicator improved (decreased) to 3.68 tons per acre in 2015 compared with 7.43 tons per acre in 1980. While the trend since 1980 shows significant improvement in per-acre soil erosion (Figure 1.15), most changes occurred before the mid-1990s, attributable in large part to implementation of conservation tillage practices, particularly on highly erodible lands. Since the late 1990s, per-acre erosion for corn has remained relatively constant (near five tons per acre). While reduced and no-tillage practices increased to roughly 25 percent each in 2005, they have since declined to 19 percent for reduced till and 21 percent for no-till, with a corresponding increase of conventional tillage to close to 60 percent. This trend, combined with more highly erodible land from the Cropland Reserve Program coming back into production over the same time period, has contributed to the interruption of the downward trend for soil conservation.

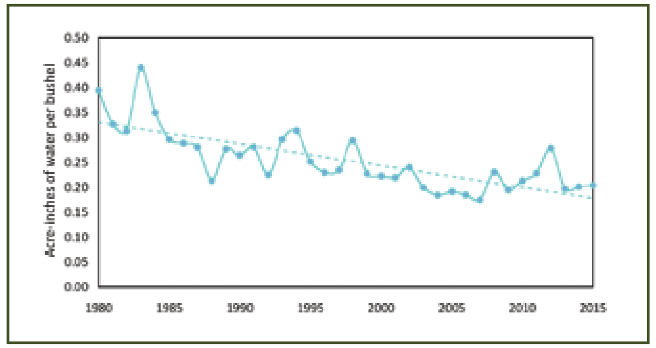


Figure 1.16. Irrigation Water Use indicator for corn for grain.

Irrigation Water Use Indicator

The Irrigation Water Use indicator also improved (decreased) over the total study period. For this indicator, extreme weather years become apparent in the annual trend (Figure 1.16). For example, a sharp increase in irrigation was seen in the extreme drought year of 2012. While the indicator improved in the three years after that event, it has remained relatively steady and is higher in 2015 than the lowest point (greatest efficiency) reached around 2004–2008.

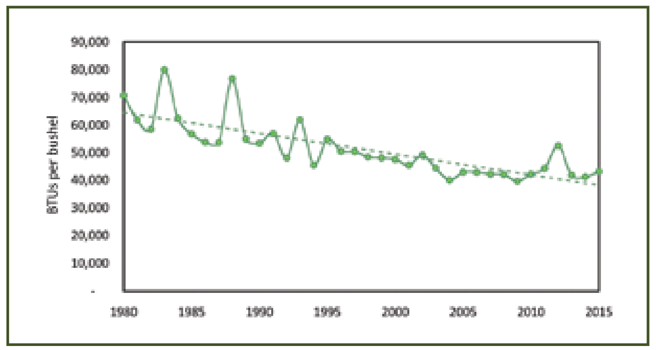


Figure 1.17. Energy Use indicator for corn for grain.

Energy Use Indicator

The Energy Use indicator (BTU per bushel) of corn for grain production improved (decreased) over the study period, decreasing from 70.9 thousand BTU per bushel in 1980 to 43.2 thousand BTU per bushel in 2015. Figure 1.17shows improvement over time, with steady declines occurring in the late 1990s and early 2000s, presumably due to decreases in tillage energy associated with increases in conservation tillage adoption. Another factor influencing the trend is nitrogen application rates, which declined on a per-bushel basis up to the mid-1990s, and then began to increase. The most recent years show a spike in 2012, likely due to low crop yields during the drought, followed by a leveling off of the downward trend.

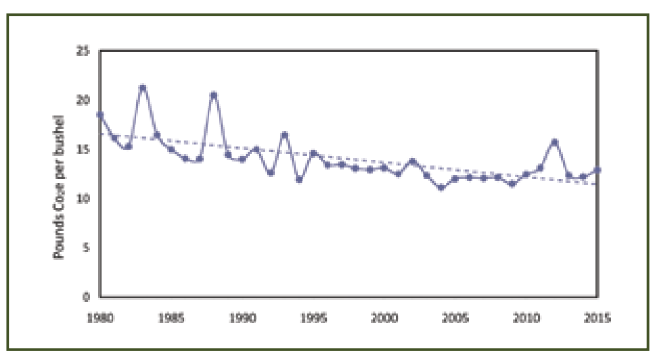


Figure 1.18. Greenhouse Gas Emissions indicator for corn for grain.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator is closely tied to the Energy Use indicator and shows a similar trend over time (Figure 1.18). Greenhouse gas emissions per bushel decreased over the study period, from approximately 18.5 pounds CO_2e per bushel in 1980 to approximately 12.9 pounds CO_2e per bushel in 2015. However, as with the Energy Use and Irrigation Water Use indicators, the 2012 drought year has been followed by a leveling off rather than a resumption of the downward trend.

PART ONE: ENVIRONMENTAL INDICATORS

CORN FOR SILAGE

While corn for grain is one of the original crops assessed by Field to Market in the previous two reports, corn for silage was not specifically evaluated. Here we consider corn grown for silage as a separate crop, as management practices, end uses, and lands used in production vary considerably from corn for grain. We are not able to calculate a separate indicator for corn for silage Soil Conservation, which is calculated directly by USDA and includes lands in corn for all uses. Thus the Soil Conservation indicator is the same as that presented for corn for grain. For corn for silage, the Land Use and Energy Use indicators have consistently improved over time, while the Greenhouse Gas Emissions indicator in the most recent period is the same as the previous period (2001–2005) (Figure 1.19). Irrigation Water Use was very low in the first period considered (1981–1985), and in the 2011–2015 period it reached that low level again.

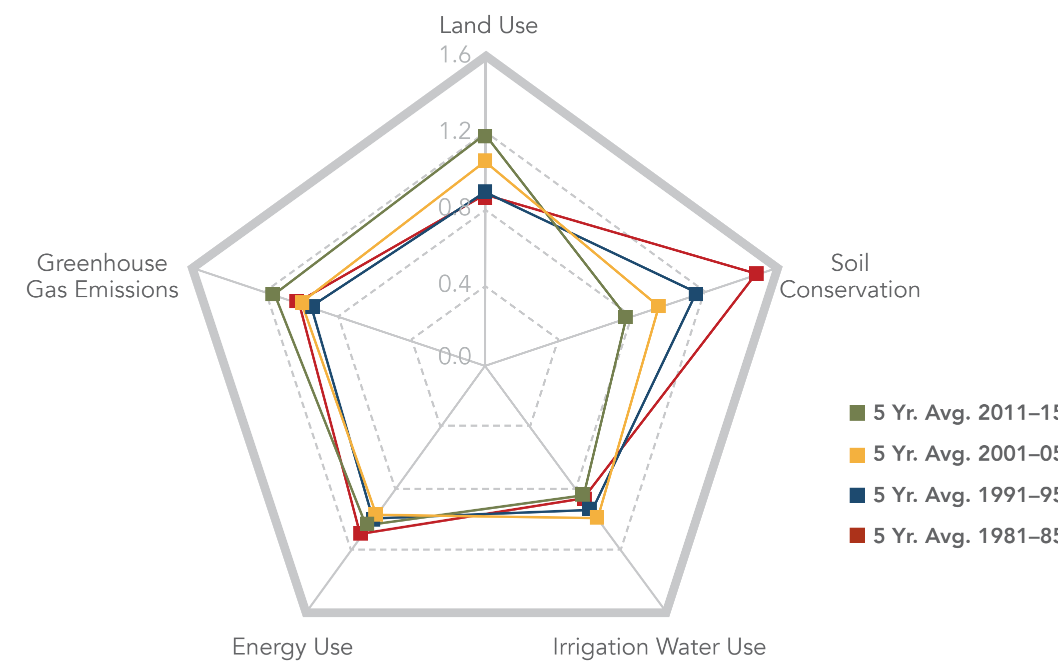


Figure 1.19. Index of resource use to produce corn for silage over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.064	Planted acres per ton
Soil Conservation	4.8	Tons per acre
Irrigation Water Use	3.027	Acre Inches per ton
Energy Use	346,099	BTU per ton
Greenhouse Gas Emissions	102.779	Pounds CO_2e per ton

** Five year average 1996–2000*

The percentage change over the full 36-year period also illustrates improvements across all five indicators of greater than 20 percent.

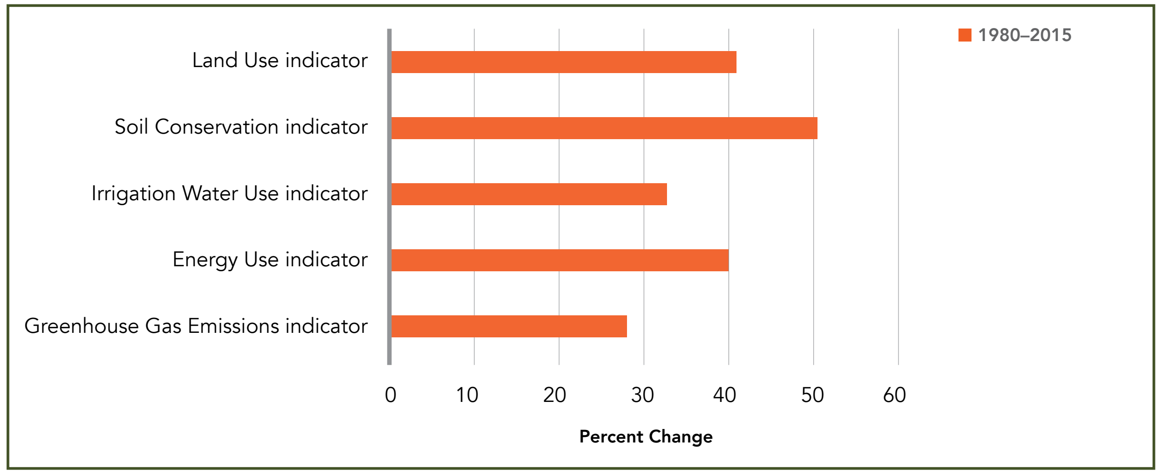


Figure 1.20. Total percentage improvement in 2015 compared to 1980 for the five indicators for corn for silage.

When considered over four equal time periods (Figure 1.21), improvements in the Land Use, Irrigation Water Use, and Energy Use indicators are seen since 2007; however, these improvements are lower in magnitude than improvements seen in the prior period.

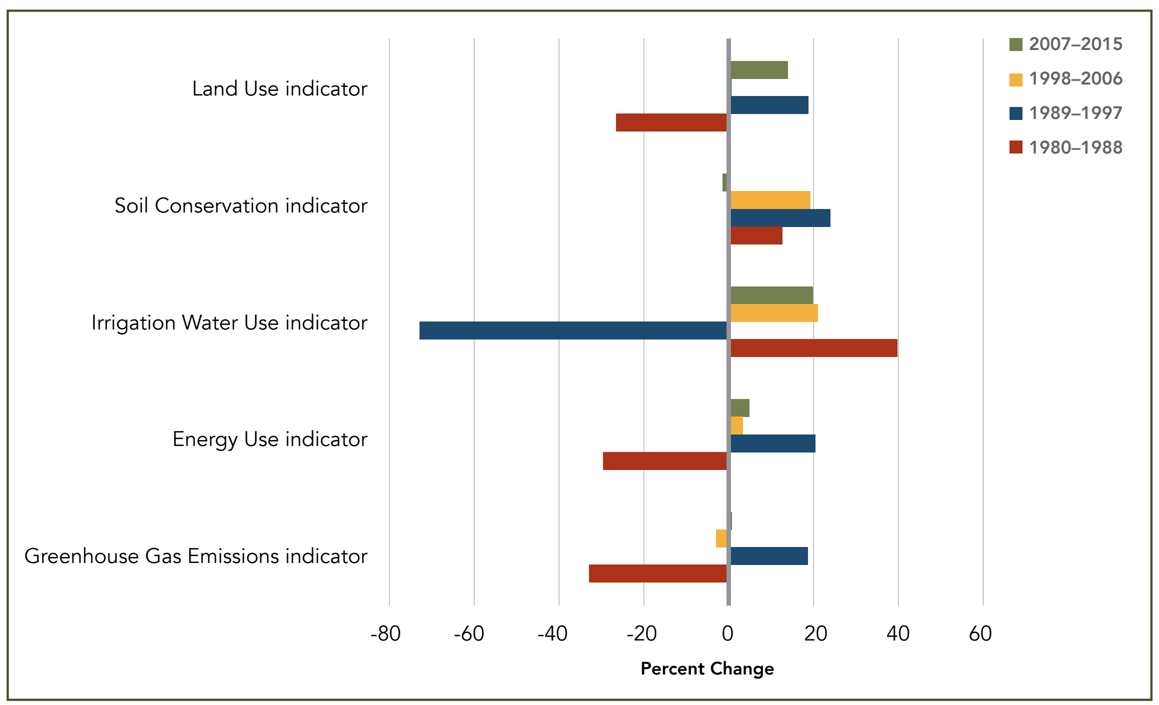


Figure 1.21. Percentage change in four equal periods for the five environmental indicators for corn for silage.

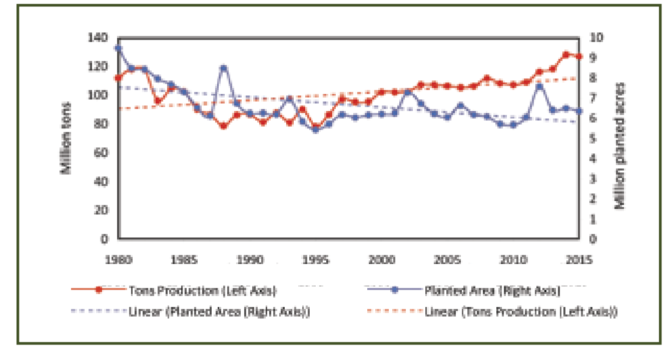


Figure 1.22. Total production and planted area for corn for silage.

Total Production and Area

The total production of corn for silage has increased over the study period, while the planted land area has declined overall to just over 6 million acres (Figure 1.22). In contrast, note that planted acreage for corn for grain was 91 million acres in 2015. Thus, where silage-specific data are not available, the aggregate corn data are more representative specifically of corn for grain. In drought years, e.g., 1988 and 2012, planted area of corn for silage increased, corresponding to a decrease in planted area for corn for grain. This likely illustrates a post-planting decision to harvest the corn for silage rather than grain given weather conditions during the growing season.

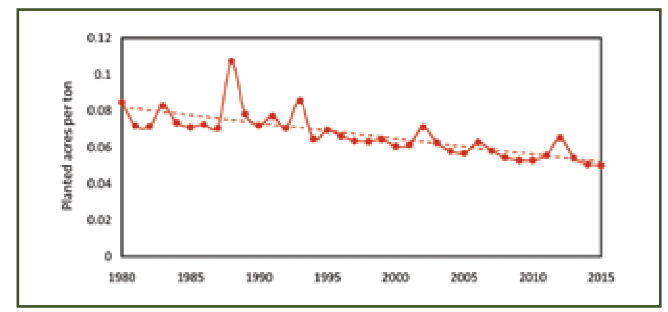


Figure 1.23. Land Use indicator for corn for silage.

Land Use Indicator

The area required per ton of corn for silage production declined moderately but steadily over the study period, with slight deviations noted in specific years, for example in the 1988 and 2012 drought years (Figure 1.23).

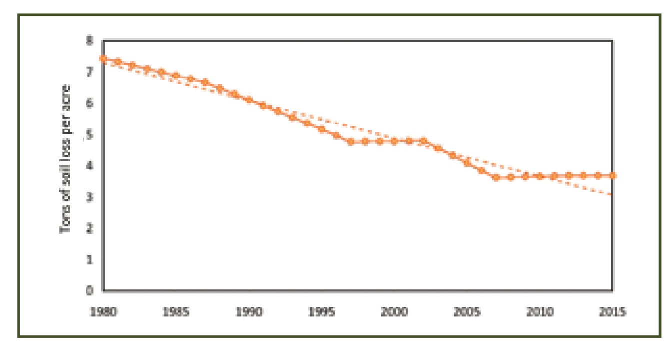


Figure 1.24. Soil Conservation indicator for corn (grain and silage).

Soil Conservation Indicator

The Soil Conservation indicator for corn for silage is the same as that for corn for grain. Given that most corn acreage in the U.S. is managed for grain (~6 million acres of corn for silage compared to ~90 million acres of corn for grain in 2015), the Soil Conservation trend is more attributable to changes in corn for grain management.

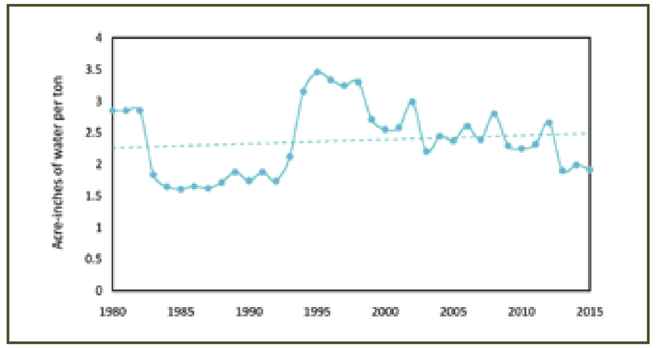


Figure 1.25. Irrigation Water Use indicator for corn for silage.

Irrigation Water Use Indicator

The Irrigation Water Use indicator displays considerable variability with no consistent trend over time, indicating that irrigation water use efficiency has not consistently improved or worsened for corn for silage production over time (Figure 1.25). The variability could be due to several factors: irrigated area for silage increased from less than 10 percent in 1980 to close to 30 percent in 2015, while the yield gain from irrigation has varied year over year.

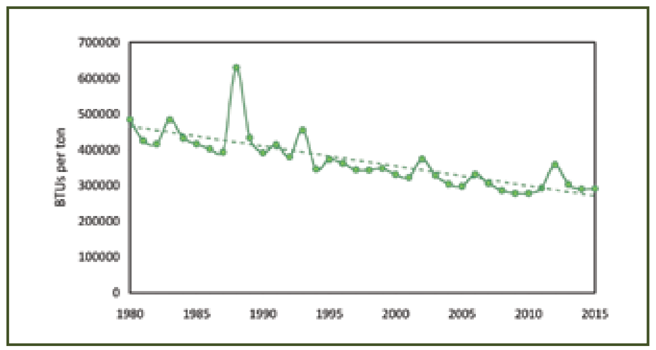


Figure 1.26. Energy Use indicator for corn for silage.

Energy Use Indicator

Energy use per ton of corn for silage declined steadily over the study period, again mirroring the improvement in yield over time and reflecting reduced energy use based on adoption of conservation tillage (Figure 1.26).

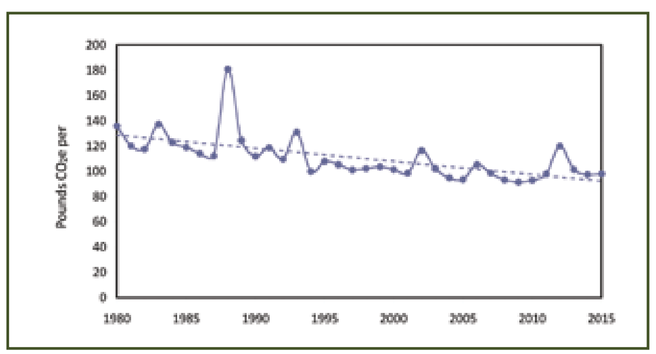


Figure 1.27. Greenhouse Gas Emissions indicator for corn for silage.

Greenhouse Gas Emissions Indicator

The greenhouse gas emissions associated with each ton of corn for silage also declined but at a slower rate than energy use (Figure 1.27).

COTTON

Over the study period (1980–2015), U.S. cotton production increased by 35 percent, with yield increases of 42 percent. Results for cotton have been adjusted to account for the production of co-products. The focus of our indicators is on the production of cotton lint; therefore, we adjust the absolute resource impacts to attribute 83 percent of the resource use to lint production and 17 percent to seed production. While this affects the total resource use reported in Appendix B, the same trends of resource use efficiency reported in this section would be the same for both lint and seed production.

Results show that the Irrigation Water Use indicator in the most recent time period (2011–2015) improved compared to prior years, continuing a trend that is evident throughout the study period (Figure 1.28). The Energy Use and Greenhouse Gas Emissions indicators also improved slightly from prior years; however, the Land Use and Soil Conservation indicators show slightly higher values than for the 2001–2005 time period.

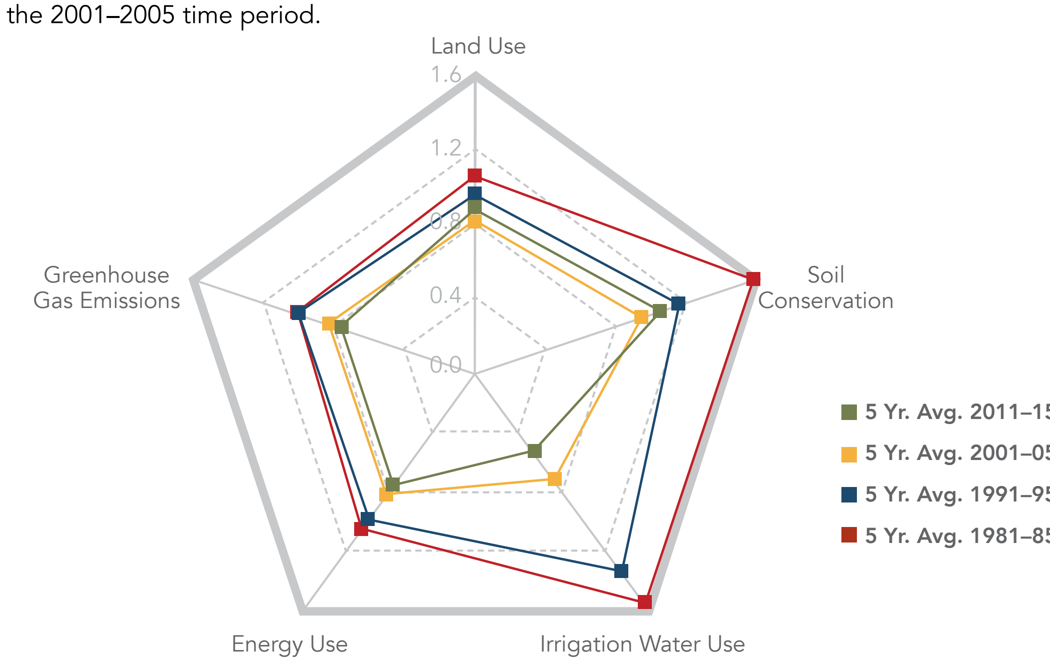


Figure 1.28. Index of resource use to produce cotton lint over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.001	Acres per pound
Soil Conservation	13.1	Tons per acre
Irrigation Water Use	0.046	Acre-in per pound
Energy Use	8,964	BTU per pound
Greenhouse Gas Emissions	2.313	Pounds CO_2e per pound

** Five year average 1996–2000*

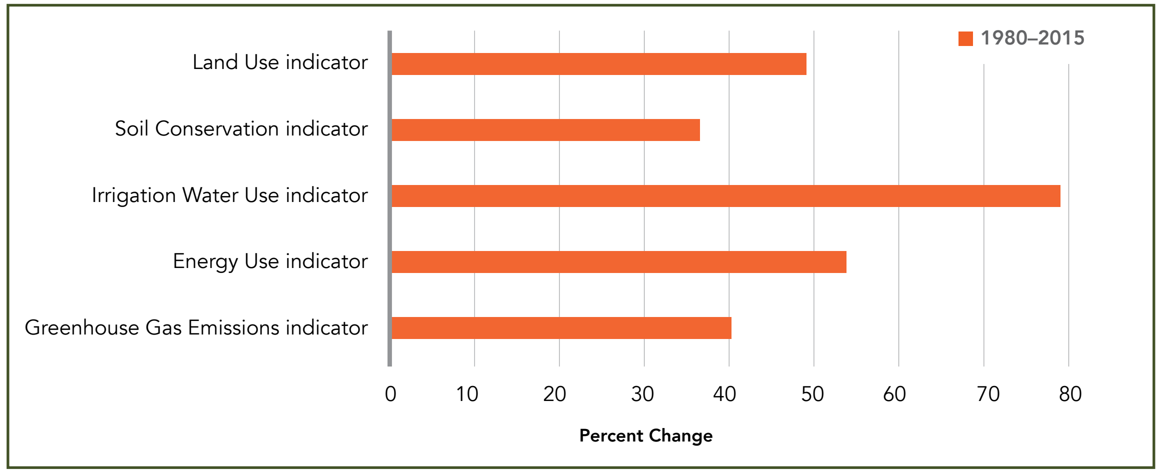


Figure 1.29. Total percentage improvement in 2015 compared to 1980 for the five indicators for cotton lint.

While the change over the 36-year period is positive (Figure 1.29), the improvements have slowed in the most recent period for all indicators (Figure 1.30), and in fact reversed for Land Use and Soil Conservation, which show negative trends in 2015 compared to 2007.

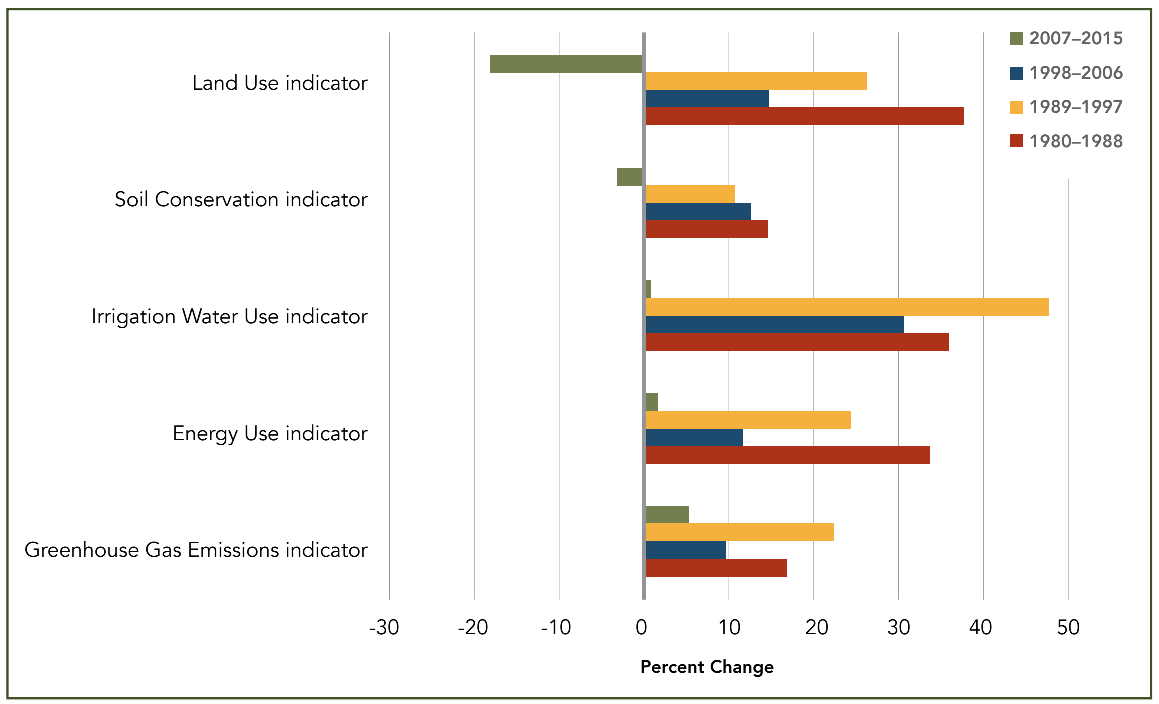


Figure 1.30. Percentage change in four equal periods for the five environmental indicators for cotton lint.

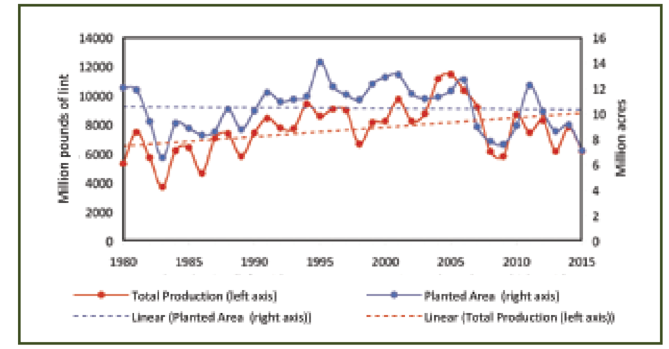


Figure 1.31. Total production and planted area of cotton lint.

Total Production and Yield

Over the study period, total production of cotton lint increased slightly, while average planted area was variable, with the highest planted acreage in the middle of the study period, and some decline seen in more recent years (Figure 1.31).

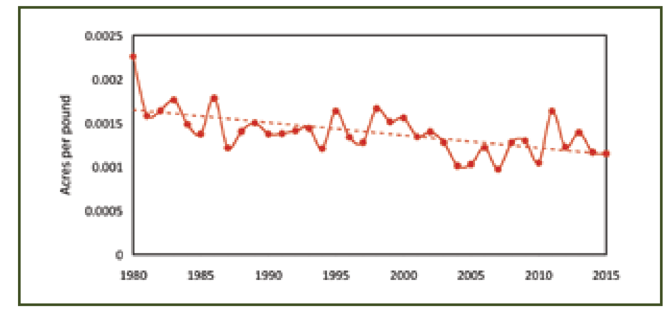


Figure 1.32. Land Use indicator for cotton lint.

Land Use Indicator

The Land Use indicator (acres per pound lint) improved (decreased) over the time period, with the lowest value occurring around 2008. Indicator values since then have been higher, although a downward trend was reestablished in the past few years (Figure 1.32).

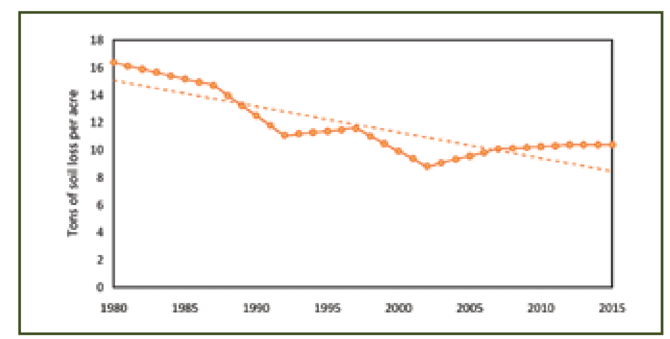


Figure 1.33. Soil Conservation indicator for cotton lint.

Soil Conservation Indicator

The Soil Conservation indicator improved (decreased) over the time period to 12.51 tons per acre in 2015 compared with 19.73 tons per acre in 1980 (Figure 1.33). While the trend since 1980 shows significant improvement in per-acre soil erosion, the largest improvement occurred in the first half of the study period, and trends in per-acre soil erosion have increased in 2007 and 2012.

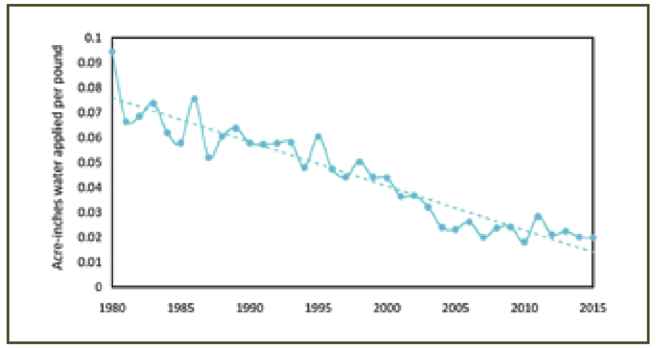


Figure 1.34. Irrigation Water Use indicator for cotton lint.

Irrigation Water Use Indicator

The Irrigation Water Use indicator has improved consistently over the study period, illustrating improvements driven by irrigation technology. Volume of water applied per incremental pound of lint produced as a result of irrigation was reduced from over 0.09 acre-inches to 0.02 acre-inches between 1980 and 2015 (Figure 1.34).

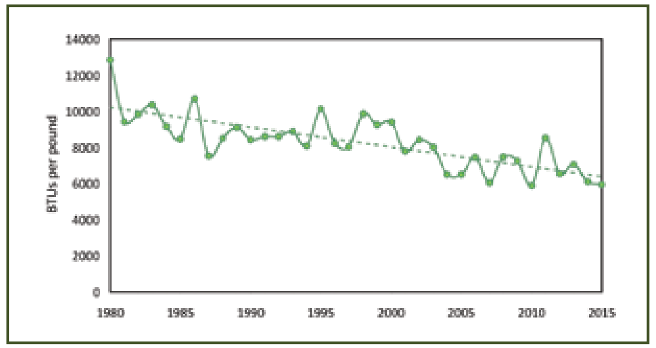


Figure 1.35. Energy Use indicator for cotton lint.

Energy Use Indicator

Over the study period, the Energy Use indicator improved (decreased) to 5,942 BTU per pound (lint) in 2015 compared to 12,900 in 1980 (Figure 1.35). Improvements in energy use efficiency per pound are driven in part by improvements in irrigation water efficiency, resulting in decreased pumping energy.

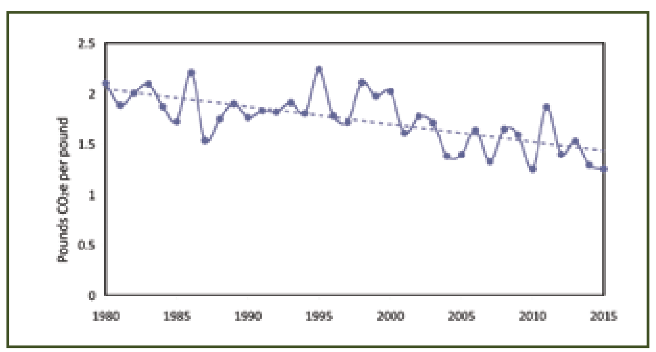


Figure 1.36. Greenhouse Gas Emissions indicator for cotton lint.

Greenhouse Gas Emissions

Over the study period, the Greenhouse Gas Emissions indicator improved (decreased) from approximately 2.1 pounds CO_2e per pound lint in 1980 to 1.3 pounds CO_2e per pound lint in 2015 (Figure 1.36). Improvements in greenhouse gas efficiency per pound are driven in part by improvements in irrigation water efficiency, resulting in decreased pumping energy and associated emissions.

PART ONE: ENVIRONMENTAL INDICATORS

PEANUTS

Peanuts are a new crop in the Field to Market program, and this is the first time they appear in the National Indicators Report. Peanuts are primarily grown in the southern and southeastern states, and total planted area has decreased since 1980, to 1.6 million acres in 2015, while production has continued to increase.

The diagram in Figure 1.37 illustrates the environmental impact per pound of peanut yield or per acre (for Soil Conservation) relative to the year 2000, and illustrates the relative efficiency of production in the most recent period (2011–2015) compared to previous years. For three of the indicators—Land Use, Energy Use, and Greenhouse Gas Emissions—the efficiency is substantially improved in the latest period when compared to earlier periods. Irrigation Water Use was very high per unit of production in the first period, and has declined since. Soil Conservation, by contrast, was lowest per acre in the first period of analysis—1981–1985. Potential driving forces for these trends are explored below with the annual graphics.

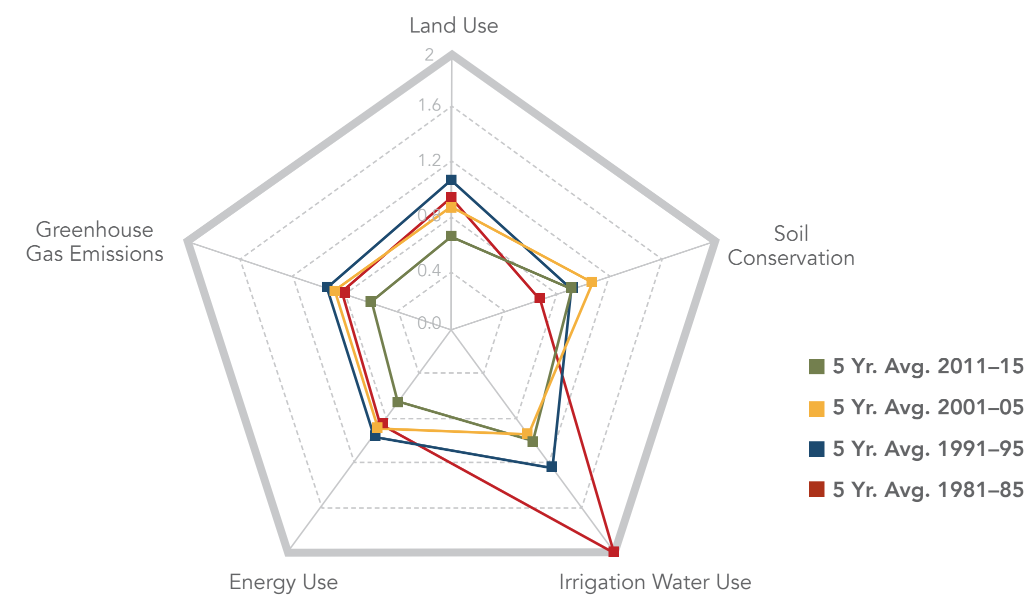


Figure 1.37. Index of resource use to produce peanuts over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.0004	Acres per pound
Soil Conservation	10.4	Tons per acre
Irrigation Water Use	0.014	Acre-in per pound
Energy Use	2,178	BTU per pound
Greenhouse Gas Emissions	0.391	Pounds CO_2e per pound

** Five year average 1996–2000*

The percentage improvement in each indicator value in 2015 when compared to the value in 1980 is illustrated in Figure 1.38, illustrating that, overall, the greatest percentage improvements have been in the Irrigation Water Use indicator. Unique among the crops in this report, and the indicators for peanuts, the overall change in Soil Conservation over the time period indicates an increase in erosion (negative indicator value).

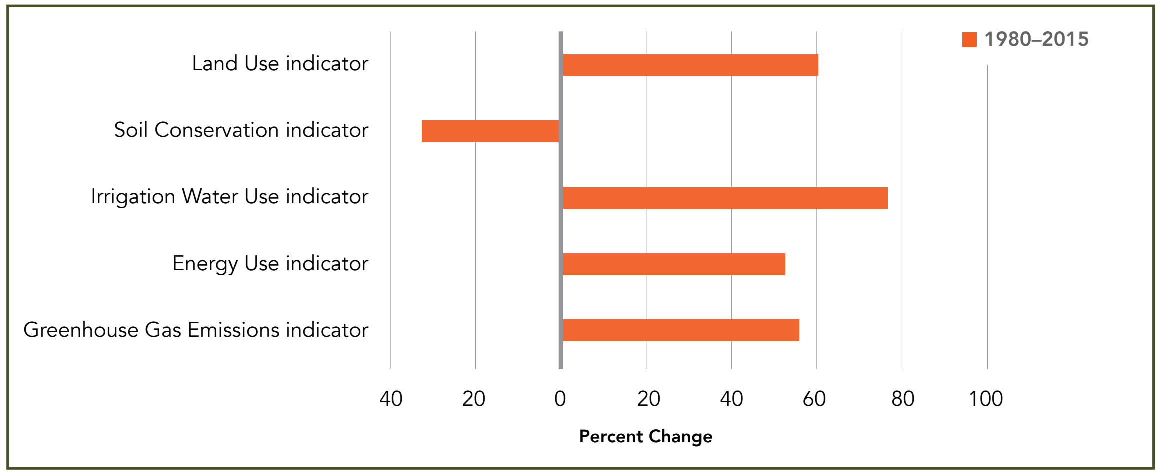


Figure 1.38. Total percentage improvement in 2015 compared to 1980 for the five indicators for peanuts.

When divided into four equal time periods, the erosion is shown to have improved (reduced) in the most recent eight-year period (2007–2015) following increases in the earlier periods. For the other indicators, improvements have also been seen in the most recent period, while earlier periods where the trend was negative are evident as well. This presentation of the results is also influenced by outlier years; in this case, the drought year of 1980 results in a very high improvement in irrigation efficiency over the first period, largely driven by the anomalously low yield of 1980.

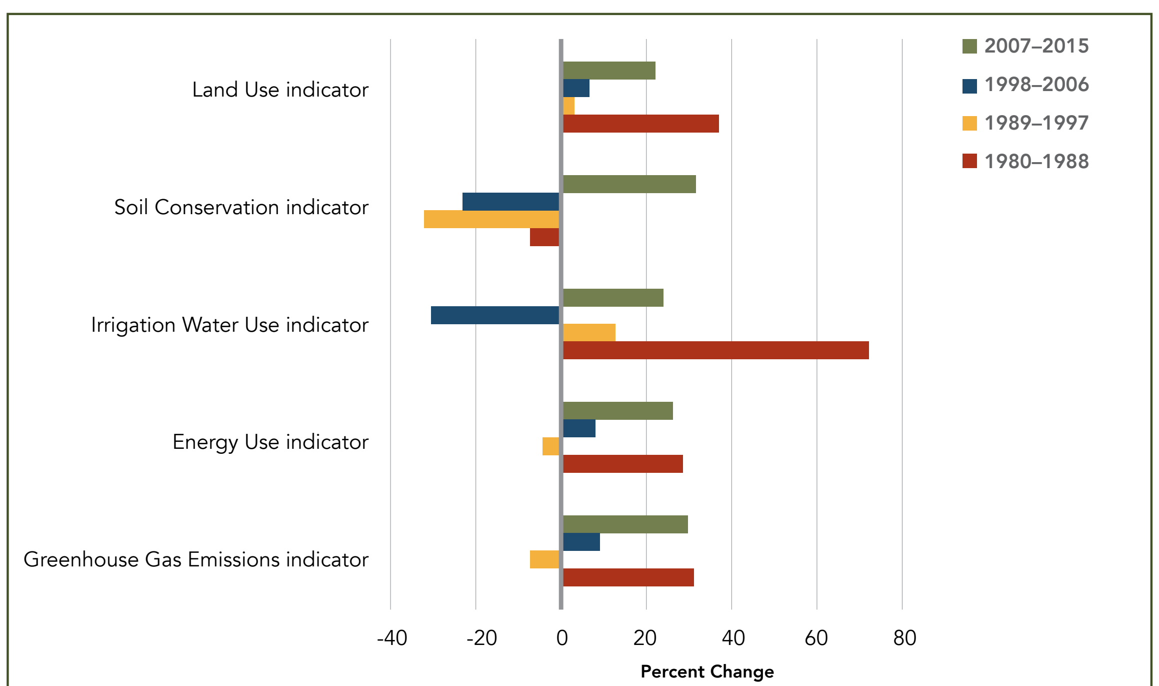


Figure 1.39. Percentage change in four equal periods for the five environmental indicators for peanuts.

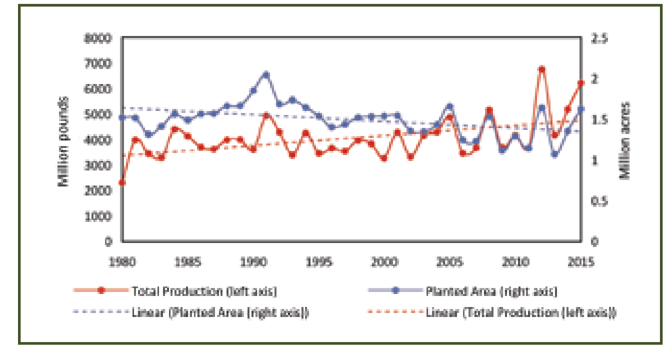


Figure 1.40. Total production and planted area for peanuts.

Total Production and Area

Total production of peanuts has increased, with significant fluctuation year over year in production. Total area planted has declined at the same time, indicating improvements in yield throughout the time period. A severe heat wave in June of 1980 throughout the southern states of the U.S. led to summer drought conditions and likely contributed to the low production of peanuts in the first year (1980). The low peanut yields in this year are evident in the results of several of the indicators below.

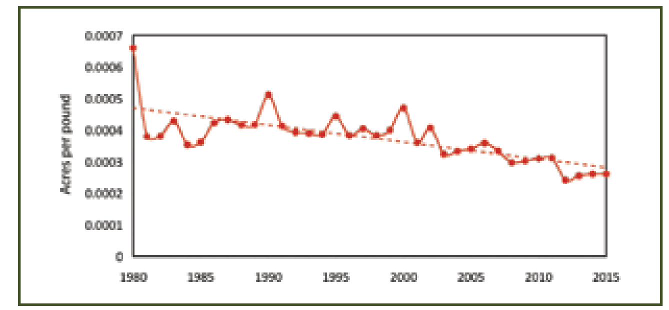


Figure 1.41. Land Use indicator for peanuts.

Land Use Indicator

The Land Use indicator represents the efficiency in terms of acres required per pound of production, and thus represents the inverse of crop yield. The declines over time in the indicator represent improvements in crop yield. The negative impact of weather events on yield in 1980 is evident in Figure 1.41.

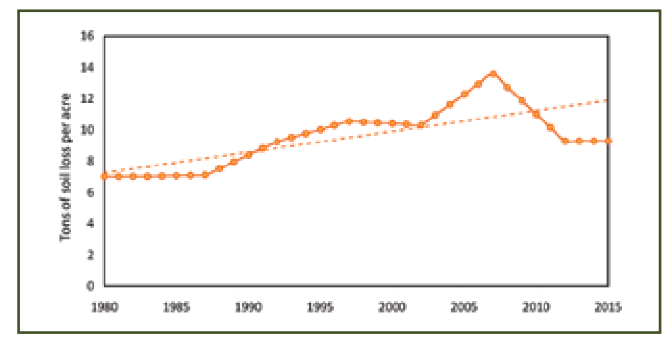


Figure 1.42. Soil Conservation indicator for peanuts.

Soil Conservation Indicator

The Soil Conservation indicator illustrates that erosion per acre increased over much of the study period, from a low of seven tons per acre in 1980 to a high of 13.6 tons per acre in 2007. After 2007, erosion declined, to 9.3 tons per acre in 2012. Peanuts are not as well suited as some of the other commodity crops to conservation tillage practices such as no-till that have driven erosion reductions illustrated in other sections of this report. While some reduced till and strip till practices can be successful, these account for a small percentage of peanut acreage, with the majority still under conventional tillage. The trend illustrated in Figure 1.42 is likely related to the shifting geography of peanut production. In the beginning of our study period, Georgia and Alabama had the highest peanut production, but that shifted to Texas in the 1990s and early 2000s before shifting back east after 2008. Erosion rates are higher in Texas than in Georgia and Alabama based on NRI simulations provided by USDA. Thus this shift in geographic area of production is likely driving the trend in the national average erosion rate.

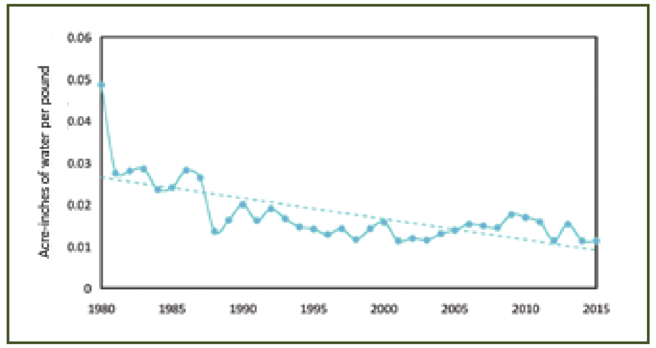


Figure 1.43. Irrigation Water Use indicator for peanuts.

Irrigation Water Use Indicator

The Irrigation Water Use indicator has declined substantially over the study period, indicating greater efficiency in irrigation used for peanuts. The trend does fluctuate some over time. The irrigation amount applied per acre (see Appendix B) also fluctuates, but overall it declines. Three factors influencing this indicator are the irrigated and non-irrigated crop yield and the irrigation amount applied.

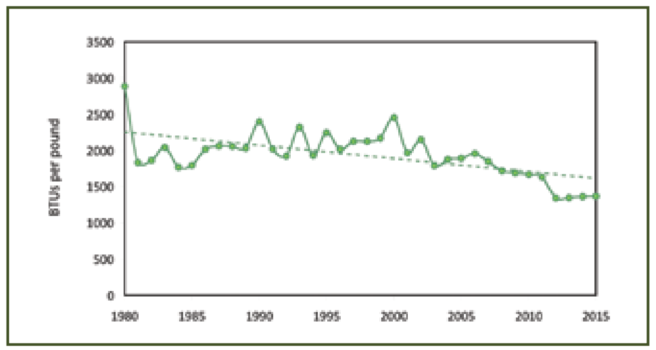


Figure 1.44. Energy Use indicator for peanuts.

Energy Use Indicator

The Energy Use indicator also declined (improved) modestly over the time period, with the majority of the improvement occurring since 2000. This indicator represents all energy used in production and is indexed to crop yield. One of the driving components is related to energy used in fertilizer production; fertilizer rates for peanuts as reported in the ARMS surveys have declined since the early 2000s, which may contribute to the improvement in energy use efficiency. In addition, increased adoption of reduced tillage practices since 1999 also contributes to the reduction in energy use.

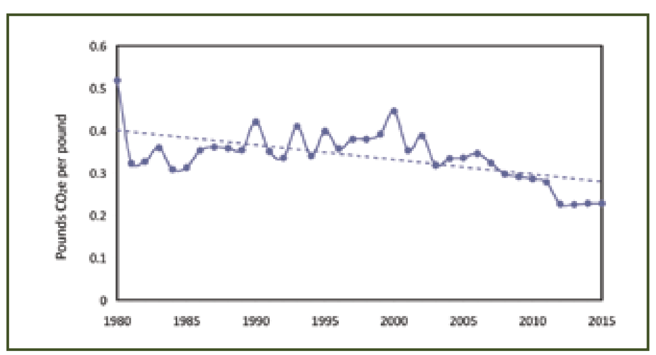


Figure 1.45. Greenhouse Gas Emissions indicator for peanuts.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator closely follows the Energy Use indicator trend. Overall, there is a decline over the study period, with most of the improvement in efficiency occurring since the early 2000s.

POTATOES

U.S. potato production has increased 28 percent since 1980, while also improving in terms of the environmental efficiency indicators included here. Figure 1.46 illustrates the overall improvement of the indicators in each successive five-year period, with particular improvements in the Soil Conservation and Irrigation Water Use indicators in the most recent period (2011–2015).

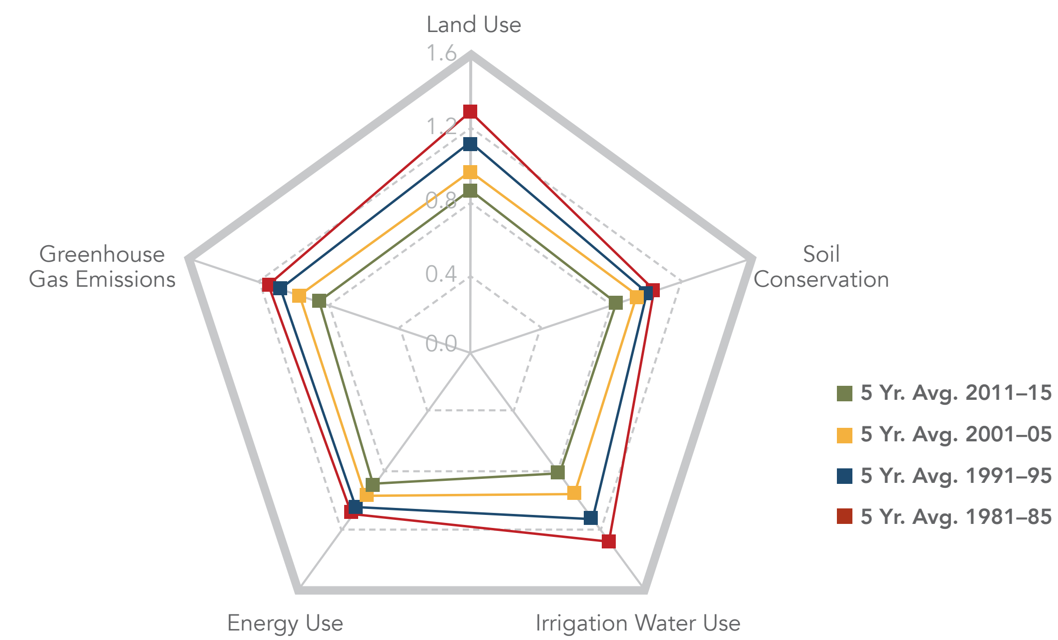


Figure 1.46. Index of resource use to produce potatoes over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.003	Acres per cwt
Soil Conservation	10.4	Tons per acre
Irrigation Water Use	0.062	Acre-in per cwt
Energy Use	70,551	BTU per cwt
Greenhouse Gas Emissions	14.830	Pounds CO_2e per cwt

** Five year average 1996–2000*

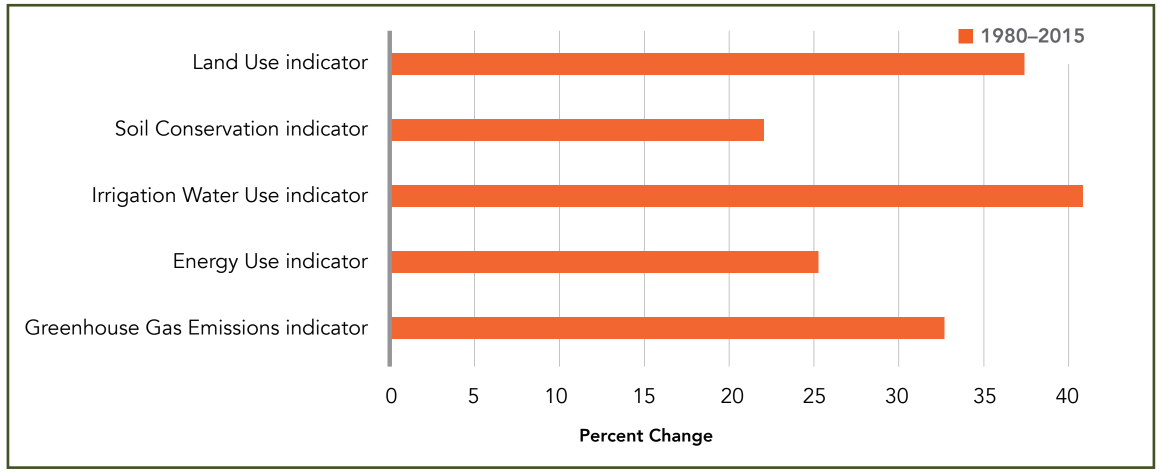


Figure 1.47. Total percentage improvement in 2015 compared to 1980 for the five indicators for potatoes.

While overall change is in a positive direction (Figure 1.47), the percentage change across four equal periods highlights that the Soil Conservation indicator was in fact 5 percent lower in 2015 compared to 2007 (Figure 1.48), indicating that erosion per acre has increased in the most recent available data. Other indicators continue to improve, with Energy Use and Greenhouse Gas Emissions seeing their greatest rate of change in the most recent period.

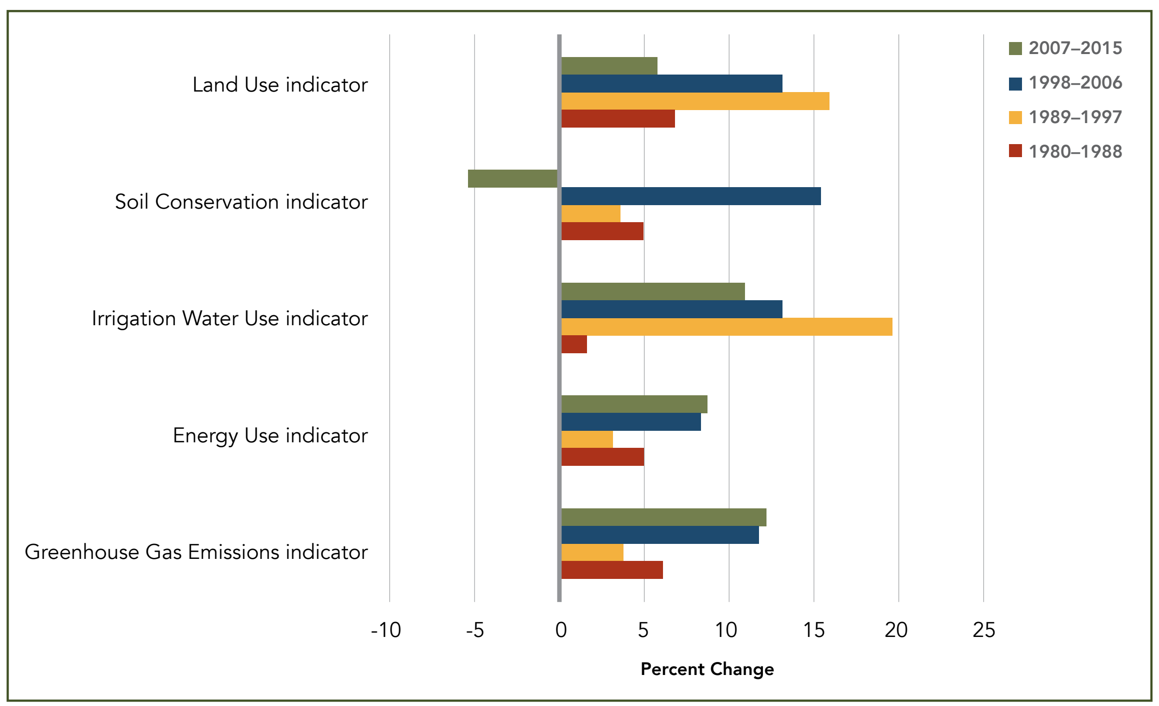


Figure 1.48. Percentage change in four equal periods for the five environmental indicators for potatoes.

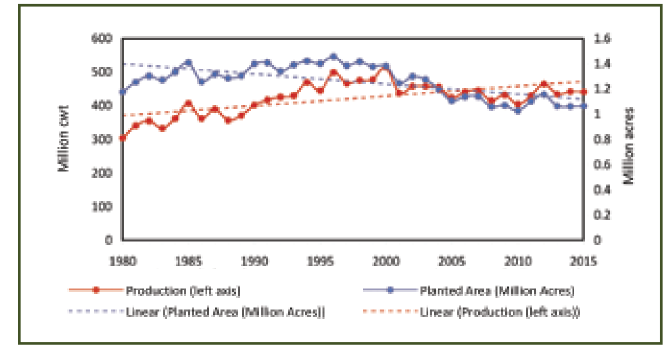


Figure 1.49. Total production and planted area of potatoes.

Total Production and Yield

Over the study period, total production increased while planted area declined (Figure 1.49), driven by increasing yield. 440 million cwt. of potatoes were produced in 2015, as compared with 304 million cwt. in 1980. This increase in production over a smaller area has been driven in part by increased irrigation as well as shifts in geographic patterns of potato cultivation.

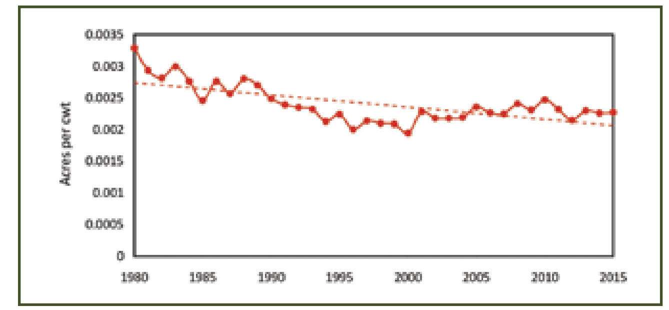


Figure 1.50. Land Use indicator for potatoes.

Land Use Indicator

Over the study period, the Land Use indicator improved (decreased) slightly. Improvement mostly occurred from 1980 to 2000, followed by an increase in the more recent third of the study period, indicating that yields have not continued to improve at the same rate in recent years.

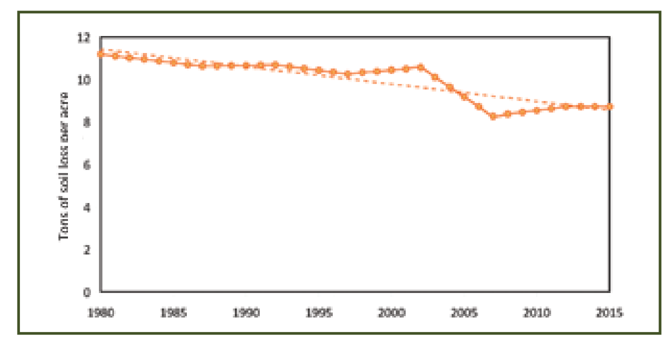


Figure 1.51. Soil Conservation indicator for potatoes.

Soil Conservation Indicator

In absolute terms, the Soil Conservation indicator decreased from 11.19 tons per acre in 1980 to 8.72 tons per acre in 2015. However, Figure 1.51 also illustrates the same trend as Figure 1.48, showing that soil erosion has increased slightly since the low point in 2007.

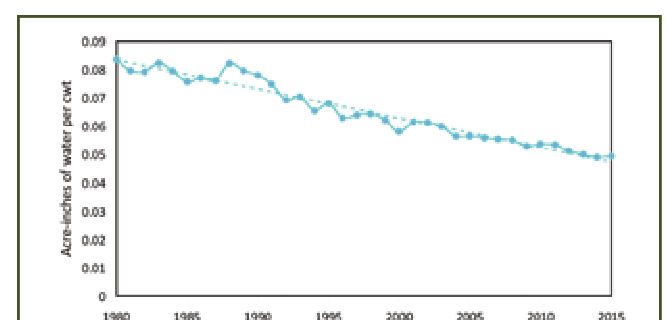


Figure 1.52. Irrigation Water Use indicator for potatoes.

Irrigation Water Use Indicator

The Irrigation Water Use indicator for potatoes improved (decreased), closely following the linear trend line for much of the study period. Over the study period, the fraction of potatoes grown with irrigation, as opposed to a rainfed system, increased from 58 percent to 88 percent, driving an increase in total irrigation water applied (see Appendix B).

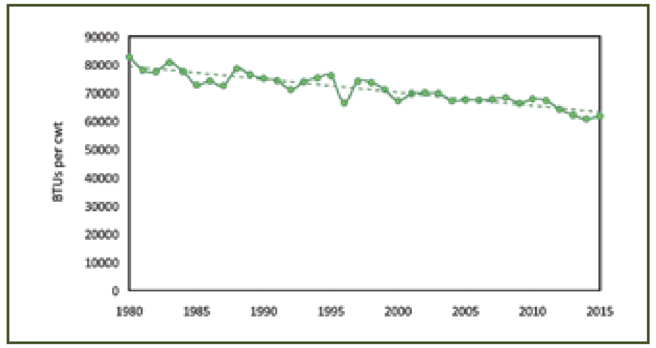


Figure 1.53. Energy Use indicator for potatoes.

Energy Use Indicator

The Energy Use indicator improved from approximately 82,700 BTU per cwt. in 1980 to 61,847 BTU per cwt. in 2015. In 2015, embedded energy in pesticides represented 13 percent of total energy use as compared to 5 percent in 1980. Embedded energy in fertilizers, on the other hand, has decreased in relative contribution to total energy use over the study period. For both embedded energy sources, however, particularly for pesticides, there is significant regional variability in application rates.

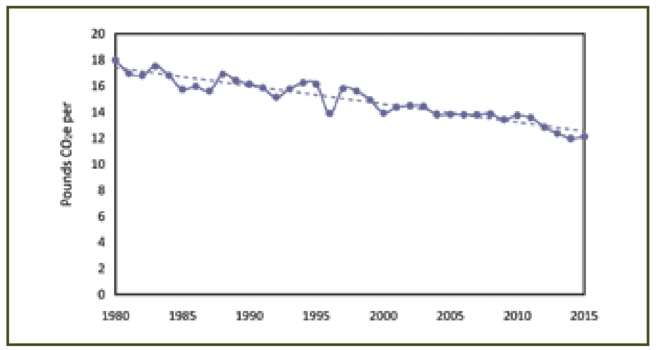


Figure 1.54. Greenhouse Gas Emissions indicator for potatoes.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator improved (decreased) over the study period, declining to 12.1 pounds of CO_2e per cwt. in 2015 compared with 18.0 pounds of CO_2e per cwt. in 1980 (Figure 1.54).

RICE

Over the study period, total U.S. rice production increased 61 percent. Figure 1.55 illustrates that the sustainability indicators for Soil Conservation and Land Use showed improvements in the most recent five-year period (2011–2015) when compared to the 2001–2005 period. However, the other indicators either held steady, or in the case of Irrigation Water Use, showed a slight increase in the most recent period.

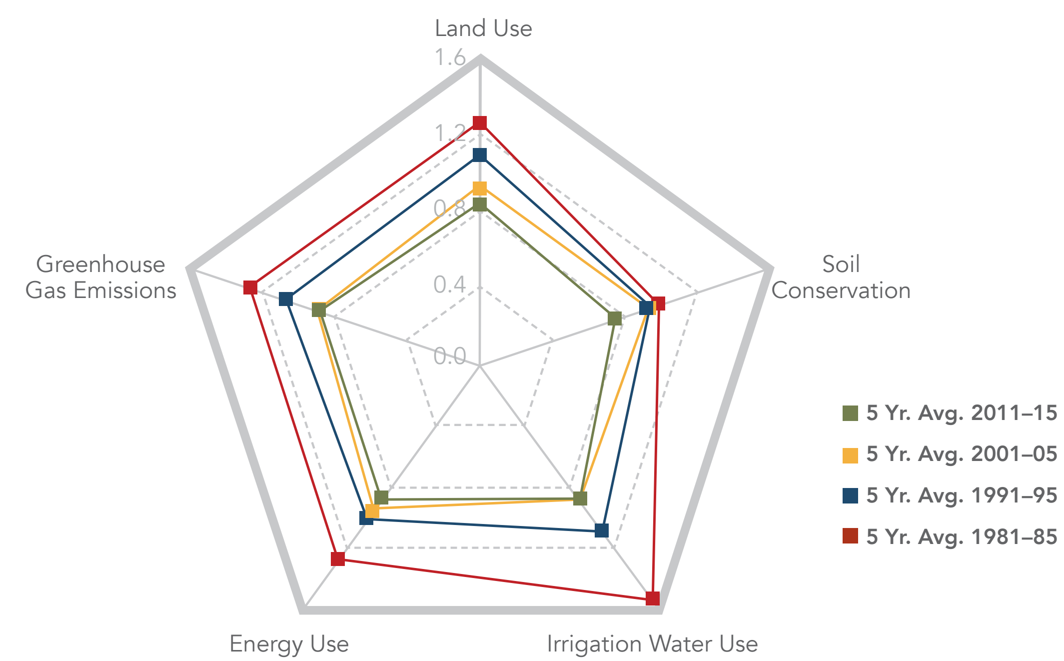


Figure 1.55. Index of resource use to produce rice over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.017	Acres per cwt
Soil Conservation	2	Tons per acre
Irrigation Water Use	0.474	Acre-in per cwt
Energy Use	226,400	BTU per cwt
Greenhouse Gas Emissions	199.47	Pounds CO_2e per cwt

** Five year average 1996–2000*

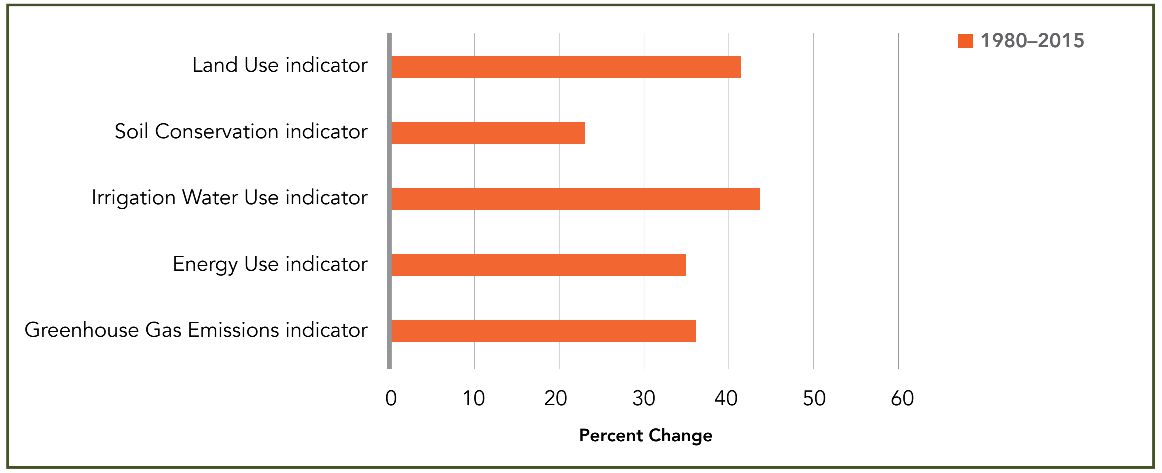


Figure 1.56. Total percentage improvement in 2015 compared to 1980 for the five indicators for rice.

When considering the trends in terms of four equal time periods representing the full period of analysis (Figure 1.56 and 1.57), the Land Use indicator is the only one that shows improvement in 2015 when compared to 2007, illustrating that much of the improvement in other indicators, in particular Irrigation Water Use and Greenhouse Gas Emissions, occurred in the earlier periods. Soil Conservation, in particular, improves in the 2011–2015 time period, as illustrated in Figure 1.55, but the overall trend from 2007 to 2015 shifts this to a slight increase in erosion over that slightly longer time period.

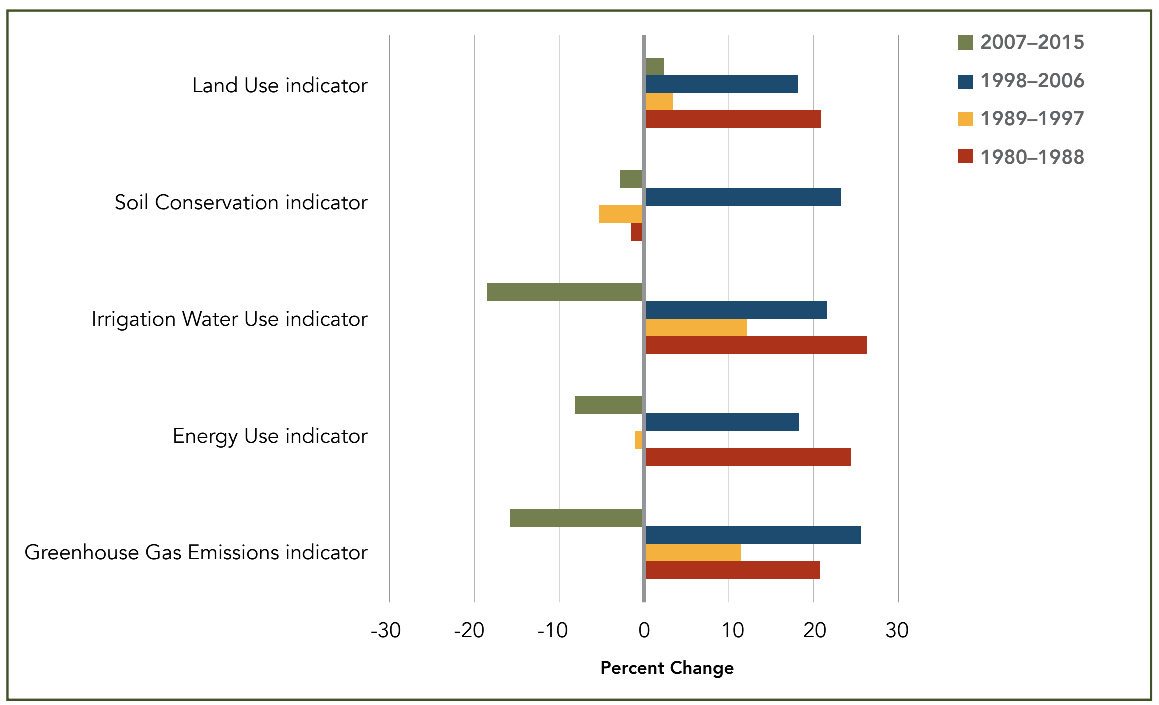


Figure 1.57. Percentage change in four equal periods for the five environmental indicators for rice.

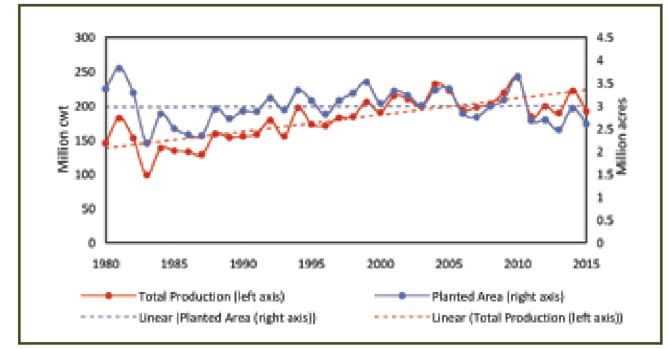


Figure 1.58. Total production and planted area of rice.

Total Production and Yield

Total production of rice increased with 192 million cwt. of rice produced in 2015 as compared with 146 million cwt. of rice produced in 1980. Improved yields over the time period allowed this increase to occur without substantial increase in the area planted for rice. While there is some variation, in recent years production and planted area followed the same trends.

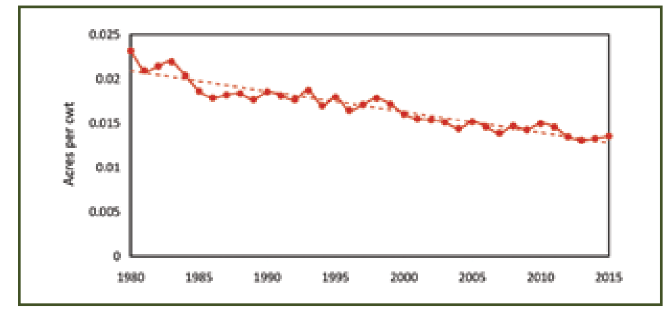


Figure 1.59. Land Use indicator for rice.

Land Use Indicator

Over the study period, the Land Use indicator (planted acres per cwt.) improved (decreased), indicating a steady improvement in yield over time, although this trend appears to have leveled off in the past three years.

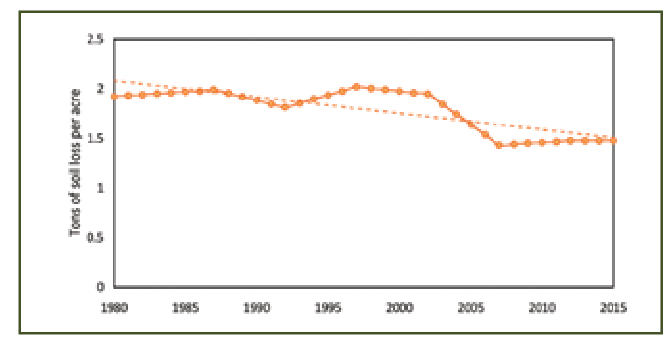


Figure 1.60. Soil Conservation indicator for rice.

Soil Conservation Indicator

On a per-acre basis, rice consistently demonstrates the lowest per-acre soil erosion of all six crops examined. This is due in part to the cultivation practices employed that are unique to rice, particularly flood irrigation and land-leveling practices. The Soil Conservation indicator showed relatively small changes over the study period, increasing in the later 1990s before declining in the early 2000s.

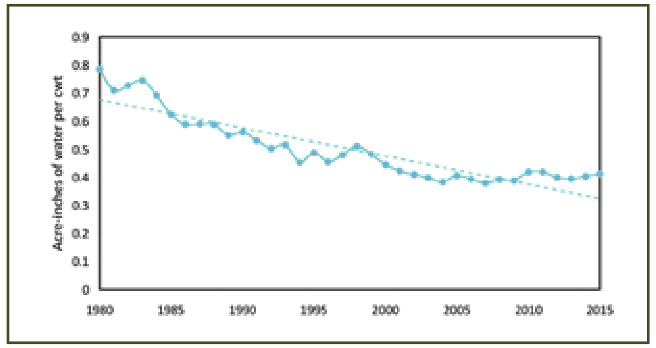


Figure 1.61. Irrigation Water Use indicator for rice.

Irrigation Water Use Indicator

The Irrigation Water Use indicator improved (decreased) over the study period, from 0.80 acre-inches per cwt. in 1980 to 0.46 acre-inches per cwt. in 2015. However, this indicator has in fact increased since 2009, returning in 2015 to the same level of efficiency as seen in 2000. All rice production in the U.S. is grown in flooded fields; therefore, irrigation is critically important to maintaining crop yields. While not reflected in this study, many rice-growing regions have made efforts in recent years to adopt practices and infrastructure to make use of reclaimed or recycled water, and to adopt practices that have been found to reduce methane emissions from wetlands.

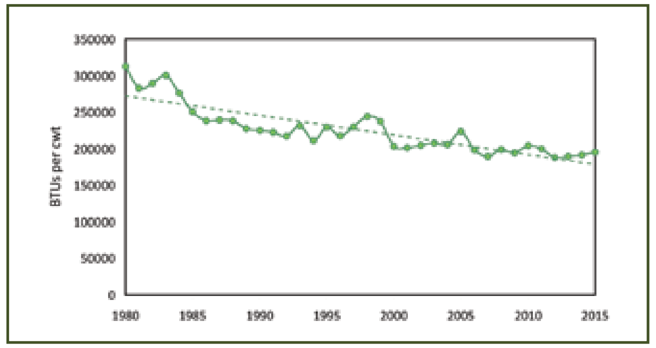


Figure 1.62. Energy Use indicator for rice.

Energy Use Indicator

The Energy Use indicator for rice decreased over the study period, primarily due to productivity gains; energy use was approximately 341,000 BTU per cwt. in 1980 and 206,364 BTU per cwt. in 2015.

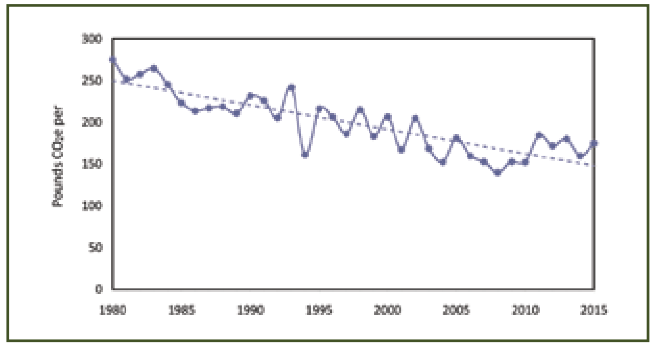


Figure 1.63. Greenhouse Gas Emissions indicator for rice.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator improved (decreased) over the study period, primarily due to improvements in productivity; emissions were approximately 276 pounds CO_2e per cwt. in 1980 and 176.6 pounds CO_2e per cwt. in 2015. Much of the interannual variation after 1990 occurs in the methane emissions estimates produced from the U.S. Greenhouse Gas Inventory (U.S. EPA, 2016).

PART ONE: ENVIRONMENTAL INDICATORS

SOYBEANS

Over the study period (1980–2011), U.S. soybean production increased substantially, by 120 percent, while planted area also increased, from 67 million acres to 82 million acres. At the same time, the key resources indicators for soybeans all demonstrated improvement. This reflects modest yield increases as well as widespread adoption of conservation tillage practices over this time period. The spidergram (Figure 1.64) illustrates that these improvements continue into the most recent period (2011–2015) for all indicators with the exception of Irrigation Water Use, which was found to be at a similar resource use efficiency level as during the 1991–1995 period.

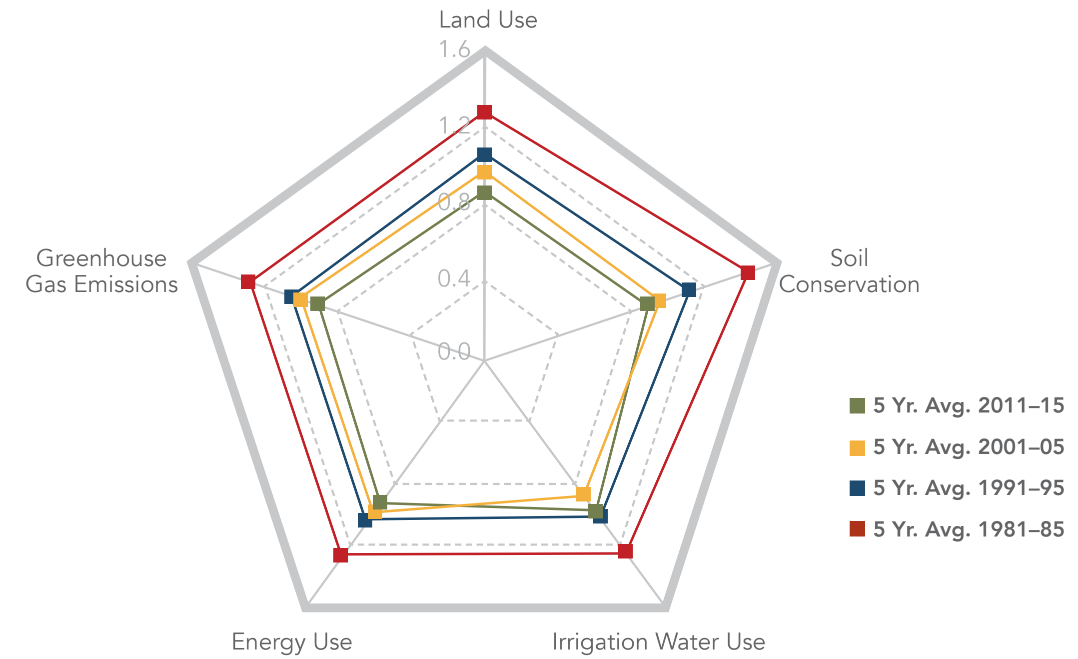


Figure 1.64. Index of resource use to produce soybeans over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	.027	Planted acres per bushel
Soil Conservation	4.7	Tons per acre
Irrigation Water Use	0.766	Acre-in per bushel
Energy Use	49,594	BTU per bushel
Greenhouse Gas Emissions	8.94	Pounds CO_2e per bushel

** Five year average 1996–2000*

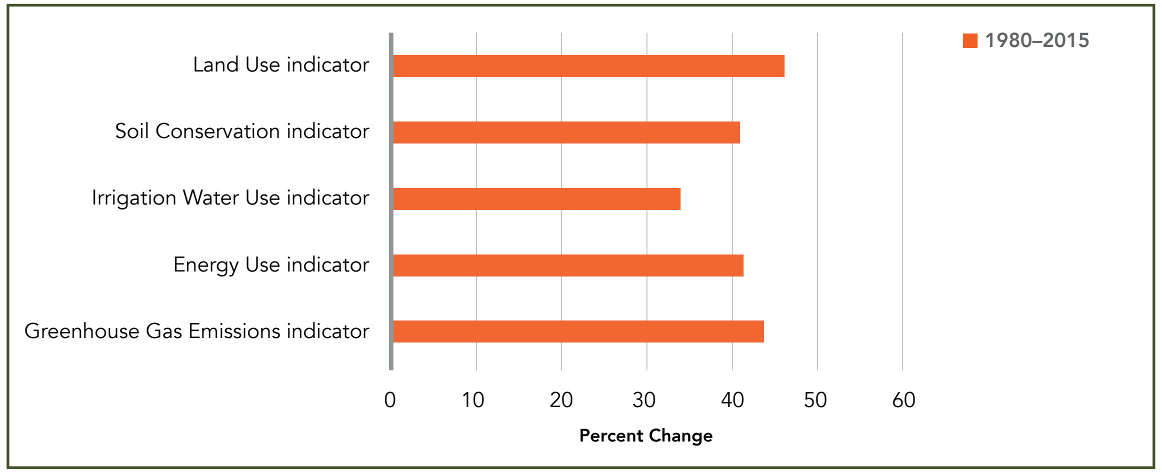


Figure 1.65. Total percentage improvement in 2015 compared to 1980 for the five indicators for soybeans.

This same trend is illustrated in Figures 1.65 and 1.66, which show the overall percentage improvement, but also that Irrigation Water Use in 2015 declined relative to 2007. Soil Conservation similarly declined (worsened) slightly over this time period, while the most recent period for the Energy Use and Greenhouse Gas Emissions indicators shows that less improvement was seen than in previous time periods.

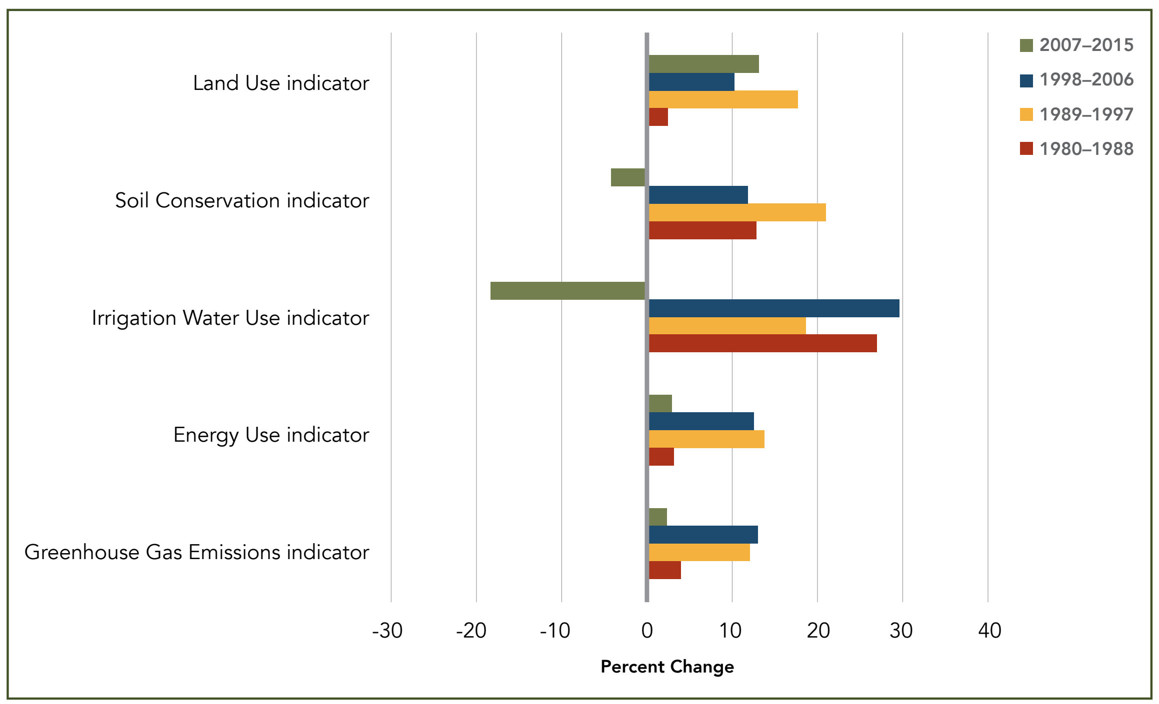


Figure 1.66. Percentage change in four equal periods for the five environmental indicators for soybeans.

PART ONE: ENVIRONMENTAL INDICATORS

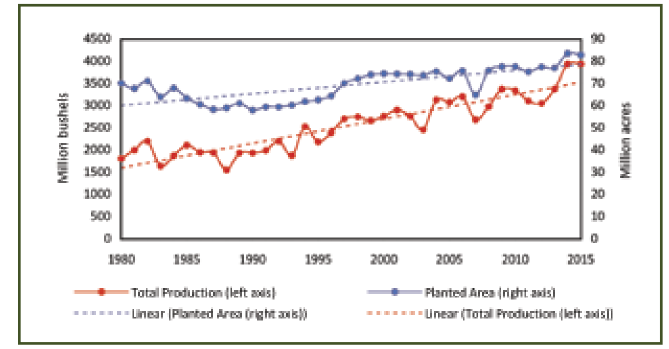


Figure 1.67. Total production and planted area of soybeans.

Total Production and Area

Total production and area of soybeans increased over the study period (Figure 1.67): 3.93 billion bushels of soybeans were produced in 2015 as compared with 1.80 billion bushels in 1980. Production increased faster than area, illustrating the role of increasing yields.

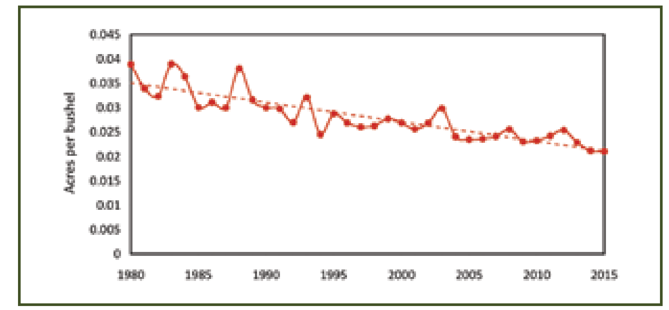


Figure 1.68. Land Use indicator for soybeans.

Land Use Indicator

Over the study period, the Land Use indicator further demonstrates improved yields by declining by 40 percent.

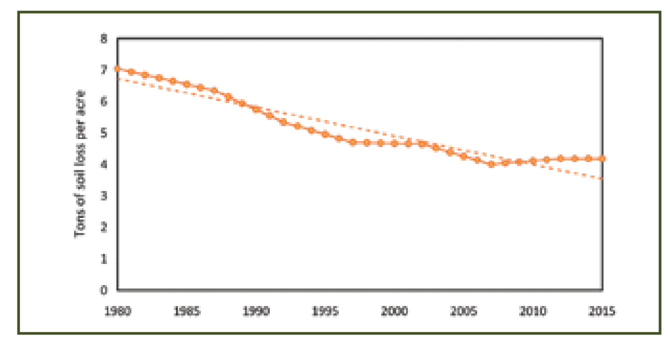


Figure 1.69. Soil Conservation indicator for soybeans.

Soil Conservation Indicator

The Soil Conservation indicator decreased (improved) from more than 7 tons per acre to 4.18 tons per acre, or 47 percent. However, since a low reached in 2007, Soil Conservation has held steady or slightly increased. This likely reflects several factors, including the same as discussed for corn, notably the leveling off of adoption rates for conservation tillage and the reduction in land in CRP. In addition, for soybeans there was a slight increase between 2005 and 2010 in acres where tillage was used as a weed management practice, in response to the increase in herbicide-resistant weeds; this trend likely was captured in the erosion estimate in 2012.

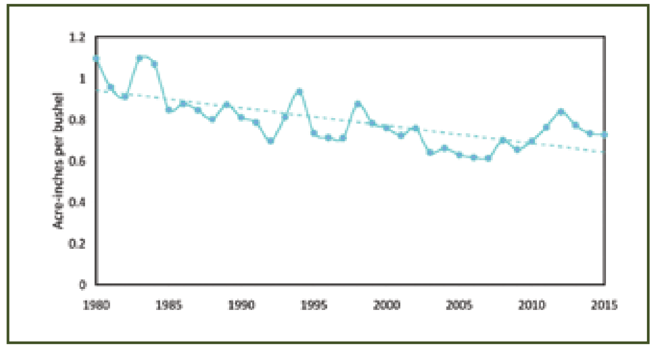


Figure 1.70. Irrigation Water Use indicator for soybeans.

Irrigation Water Use Indicator

The Irrigation Water Use indicator improved, from 1.09 acre-inches per bushel in 1980 to 0.73 acre-inches per bushel in 2015. Over the same time period, the percentage of soybean acreage irrigated increased from 4 percent to 9 percent. An anomalously high value was observed in 2012, corresponding with a severe drought in the Midwest. Since then, the indicator has declined again, to 0.73, and remains higher than the lowest value (0.61) from 2007.

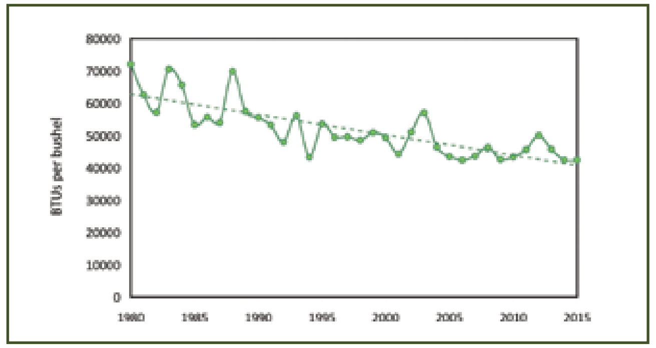


Figure 1.71. Energy Use indicator of soybeans.

Energy Use Indicator

The Energy Use indicator improved (decreased) 35 percent over the study period, from 74,000 BTU per bushel in 1980 to 42,434 BTU per bushel in 2015. Energy use for producing crop chemicals (embedded energy) and irrigation for soybeans have increased over time; however, these increases have been offset by decreases in tillage energy with the increase in conservation tillage (reduced and no-till) to roughly 70 percent of soybean acres in 2015.

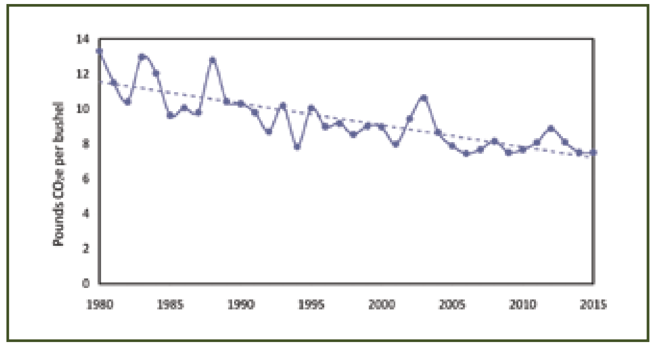


Figure 1.72. Greenhouse Gas Emissions indicator of soybeans.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator also improved (decreased) over the study period, from 13.6 pounds CO_2e per bushel in 1980 to 7.5 pounds CO_2e per bushel in 2015. Sensitive to the same drivers as the Energy Use indicator, the increase in energy associated with crop chemicals and irrigation has been offset by reduced energy use and associated emissions from fewer tillage operations.

SUGAR BEETS

This is the first inclusion of sugar beets in the Field to Market indicators report. Overall, the environmental indicators in the latest five-year period (2011–2015) are significantly improved compared with the earlier five-year periods. For the first three periods, there is little difference in Land Use, Energy Use, and Greenhouse Gas Emissions. For Irrigation Water Use there is a consistent trend of improvement, while for Soil Conservation, the first and final periods have the lowest values.

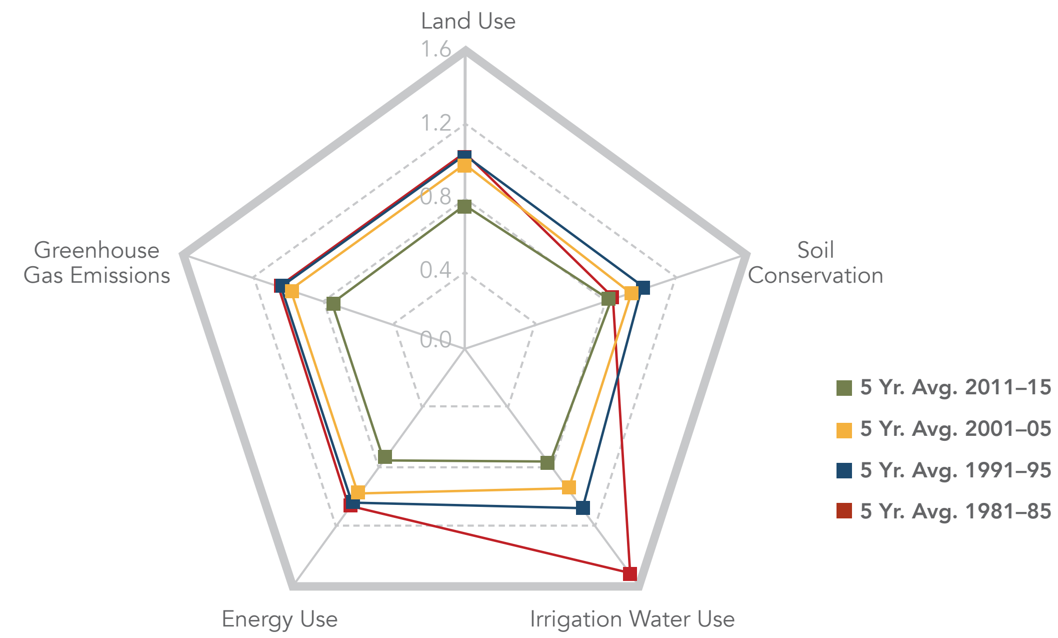


Figure 1.73. Index of resource use to produce sugar beets over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.048	Planted acres per ton
Soil Conservation	10.21	Tons per acre
Irrigation Water Use	4.68	Acre Inches per ton
Energy Use	423,695	BTU per ton
Greenhouse Gas Emissions	92.54	Pounds CO_2e per ton

** Five year average 1996–2000*

Overall percentage change in 2015 when compared with 1980 also indicates improvements in the indicators per unit of production, with a very small percentage improvement in soil conservation (Figure 1.74).

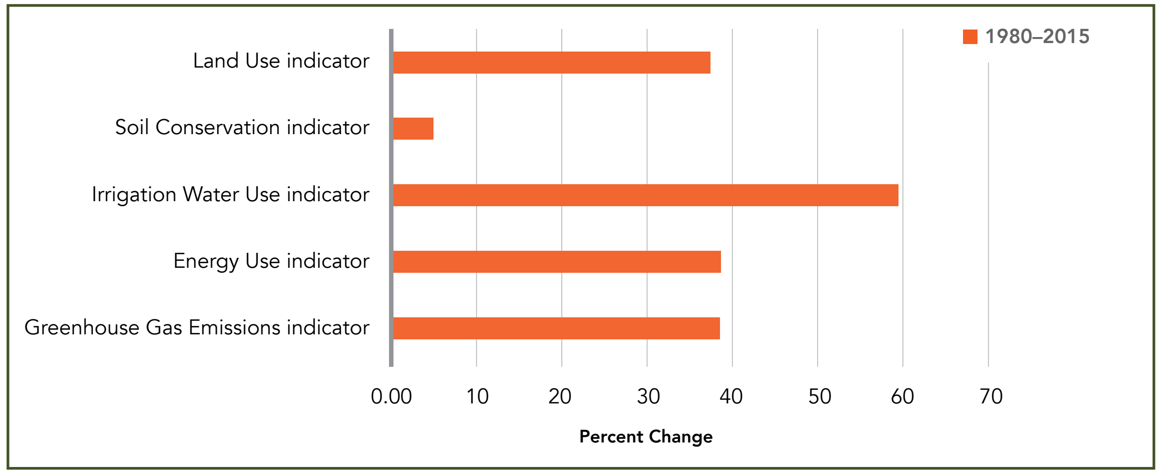


Figure 1.74. Total percentage improvement in 2015 compared to 1980 for the five indicators for sugar beets.

When examined in each of four equal periods, the indicators illustrate strong improvement in 2015 compared with 2007, with the negative trends in indicators occurring in the first half of the study period (Figure 1.75).

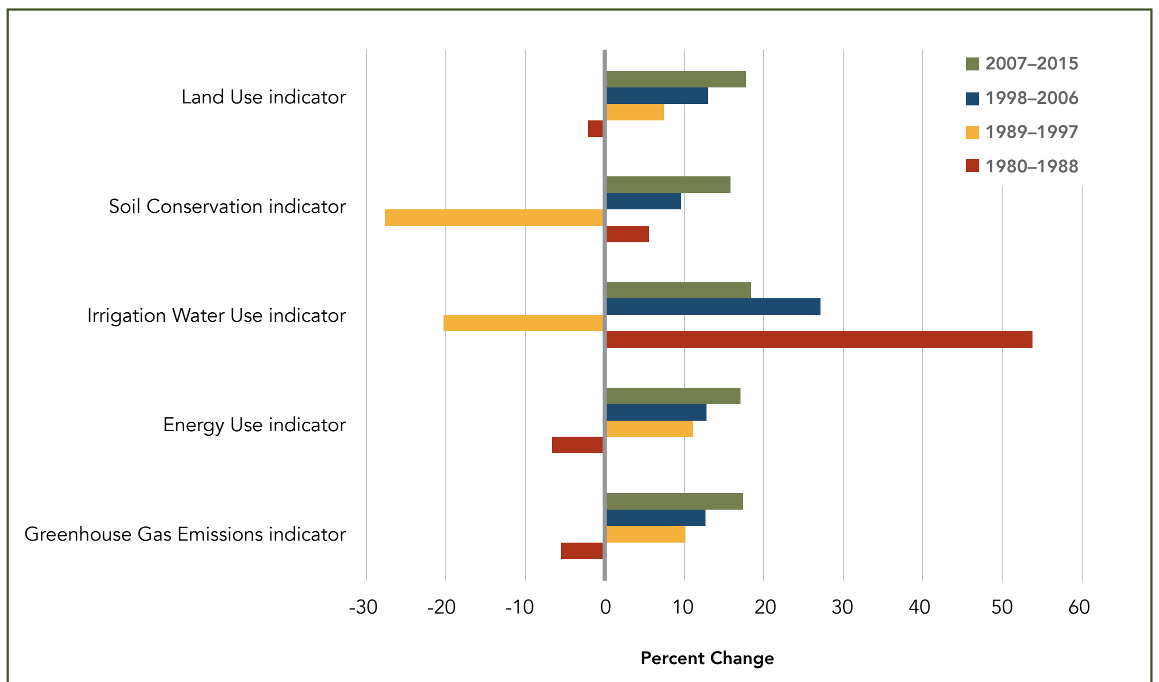


Figure 1.75. Percentage change in four equal periods for the five environmental indicators for sugar beets.

Total Production and Planted Area

Total production of sugar beets increased over the time period, with a steady to decreasing trend in planted area indicating that most of the production increase has occurred due to crop yield improvements (Figure 1.76).

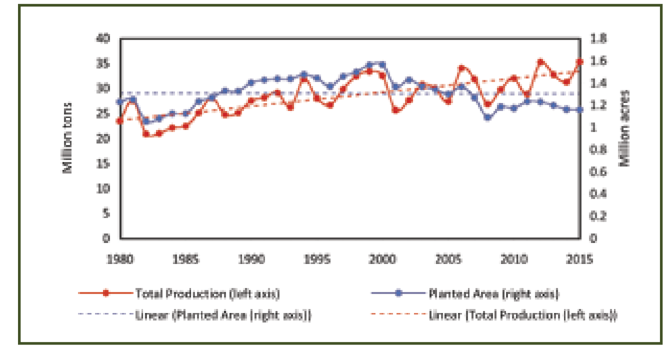


Figure 1.76. Total production and planted area for sugar beets.

Land Use Indicator

The Land Use indicator further illustrates this yield improvement, with an overall decline over the course of the study period (Figure 1.77).

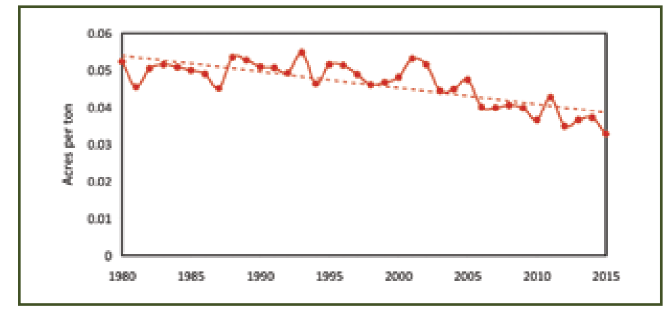


Figure 1.77. Land Use indicator for sugar beets.

Soil Conservation Indicator

The Soil Conservation indicator does not exhibit a consistent trend. While the most recent years—since 2005—have seen a decline in soil erosion, there was a substantial increase from the mid-1980s to mid-1990s that influences the trend over the full period of analysis. Tillage data are not available specifically for sugar beets; however, conservation tillage is not typically practiced. Erosion rates therefore likely reflective of other management changes. Surveys of sugar beet producers from North Dakota State University, for example, have found that the number of cultivation operations for weed control have declined since the early 2000s.

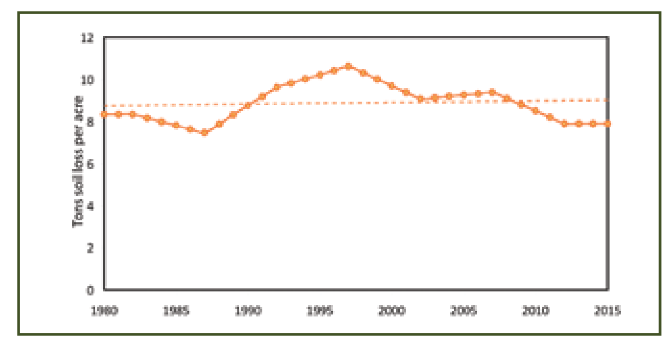


Figure 1.78. Soil Conservation indicator for sugar beets.

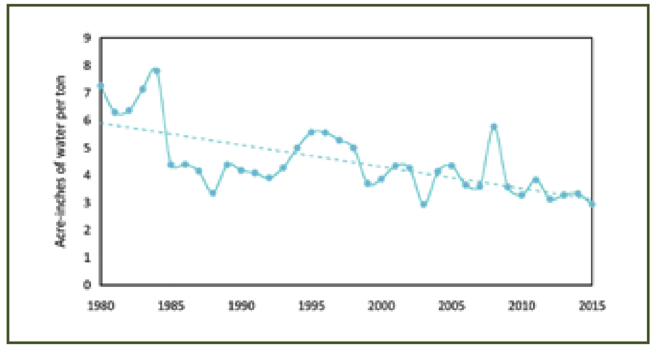


Figure 1.79. Irrigation Water Use indicator for sugar beets.

Irrigation Water Use indicator

Irrigation Water Use for sugar beets has declined over time, indicating greater efficiencies in water application, despite some variability apparent in the data.

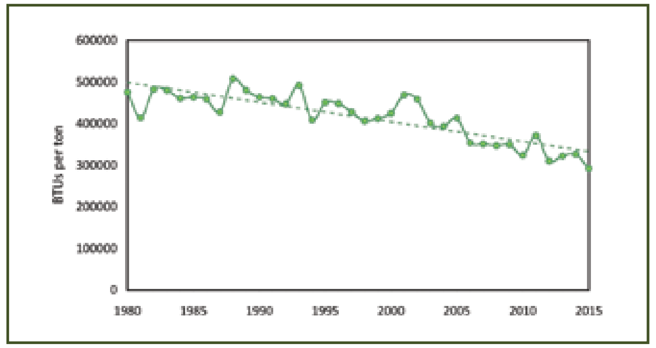


Figure 1.80. Energy Use indicator for sugar beets.

Energy Use Indicator

The Energy Use indicator declined over time at a relatively steady rate, with the lowest energy use per ton in 2015.

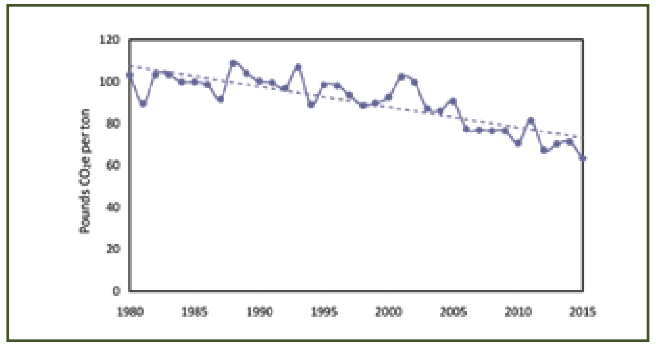


Figure 1.81. Greenhouse Gas Emissions indicator for sugar beets.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator declined, following a pattern similar to that for Energy Use.

WHEAT

Wheat is one of the original crops assessed in the previous two reports; for the purposes of the national indicators, we consider all wheat (winter and spring grown) in one aggregate measure. Over the study period (1980–2015), trends in U.S. wheat production show some similarity to barley, with an overall decline of 17 percent. However, the environmental indicators all improved for wheat when considered over the full time period, similar to other crops and reflecting both improvements in yield and in adoption of conservation practices. In Figure 1.82, the progress on each sustainability indicator shows improvement on all five in the most recently assessed time period (2011–2015) compared to earlier time periods. The greatest improvements are observed in the Irrigation Water Use, Soil Conservation, and Energy Use indicators.

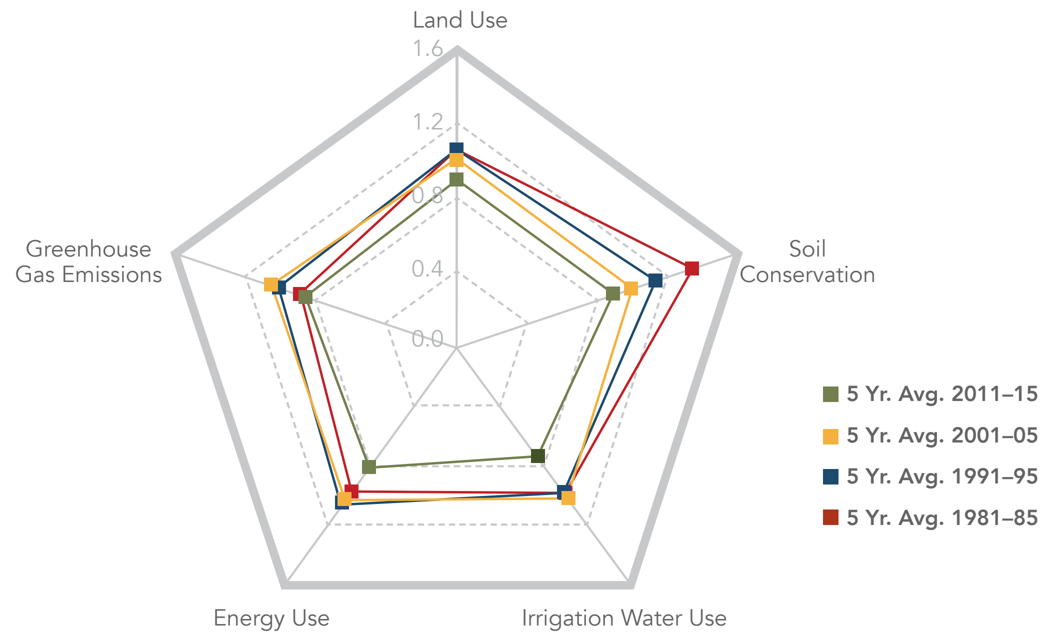


Figure 1.82. Index of resource use to produce wheat over time.

Data are presented in index form, where the year 2000 = 1 and a 0.1 point change is equal to a 10 percent difference. Index values allow for comparison of change across multiple dimensions with differing units of measure. Year 2000 values are provided in the table.

	2000 *	Unit
Land Use	0.029	Planted acres per bushel
Soil Conservation	5.3	Tons per acre
Irrigation Water Use	0.58	Acre-in per bushel
Energy Use	95,110	BTU per bushel
Greenhouse Gas Emissions	23.88	Pounds CO_2e per bushel

** Five year average 1996–2000*

These trends are further explored in Figures 1.83 and 1.84, which illustrate that the greatest improvement over the full period was in Soil Erosion, with the least improvement in Greenhouse Gas Emissions. When considered as the change in each of four equal time periods, there appear to be two periods marking improvement over time, with two marking negative change in the indicators. In 1997 compared to 1989 and in 2015 compared to 2007, all five indicators show positive trends (Figure 1.84), while the opposite is true for the other periods. Note that the drought of 1988 is also apparent in wheat production, which affects several of the indicators, in particular contributing to the negative trends for Land Use, Energy Use, and Greenhouse Gas Emissions in the first period assessed, as shown in Figure 1.84.

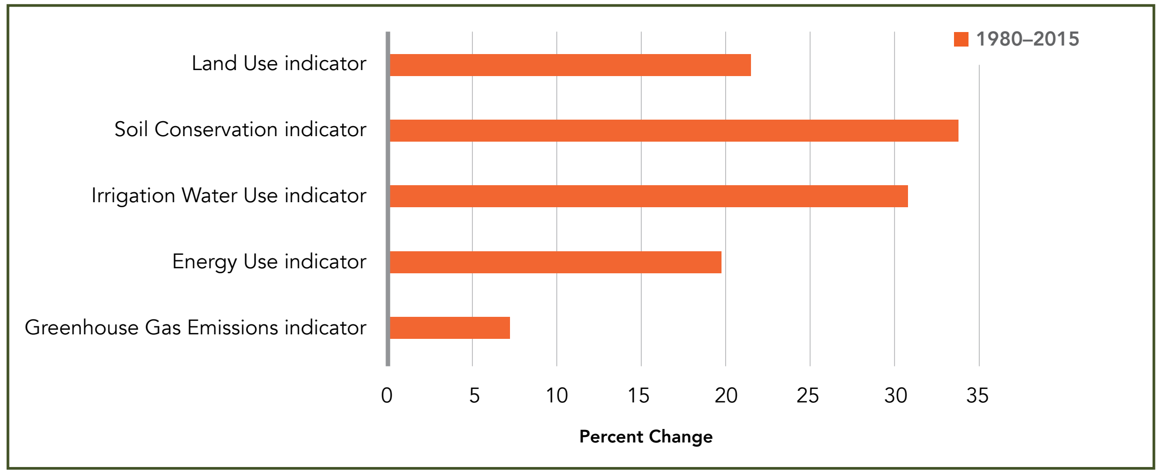


Figure 1.83. Total percentage improvement in 2015 compared to 1980 for the five indicators for wheat.

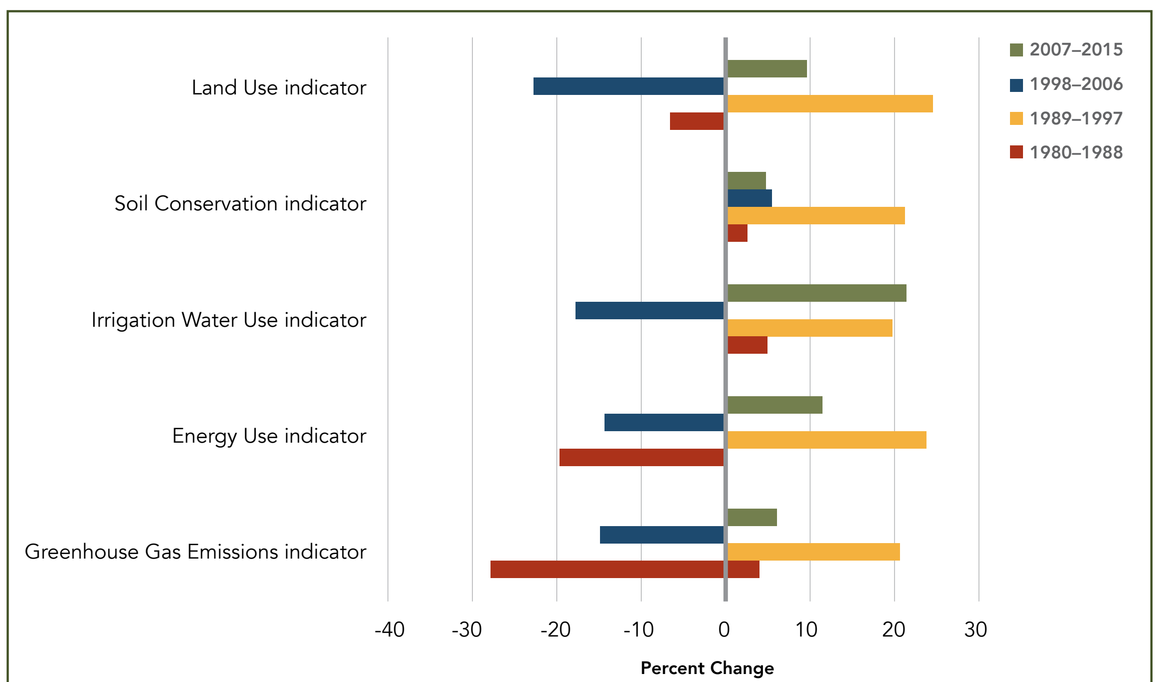


Figure 1.84. Percentage change in four equal periods for the five environmental indicators for wheat.

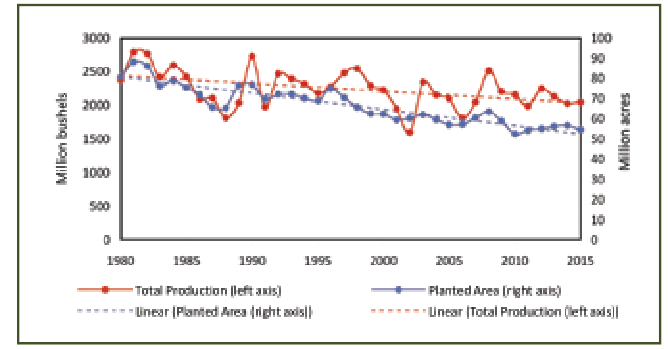


Figure 1.86. Total production and planted area of wheat.

Total Production and Area

Total production of wheat decreased to 2.05 billion bushels in 2015 as compared with 2.3 billion bushels in 1980. Planted area also decreased to 57 million acres from more than 80 million acres in 1980 (Figure 1.85).

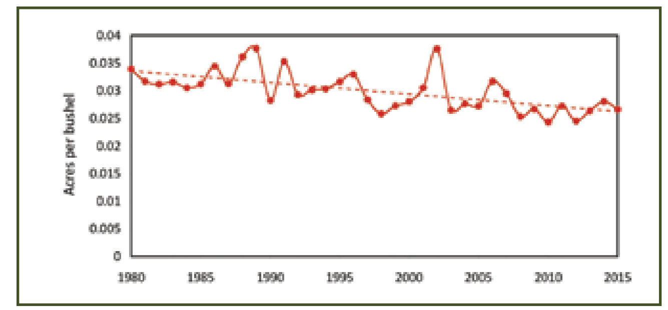


Figure 1.87. Land Use indicator for wheat.

Land Use Indicator

Over the study period, the Land Use indicator (acres per bushel) improved (decreased), reflecting an increase in yield. The trend shows some variation over the year while holding relatively steady from 2008 to 2015.

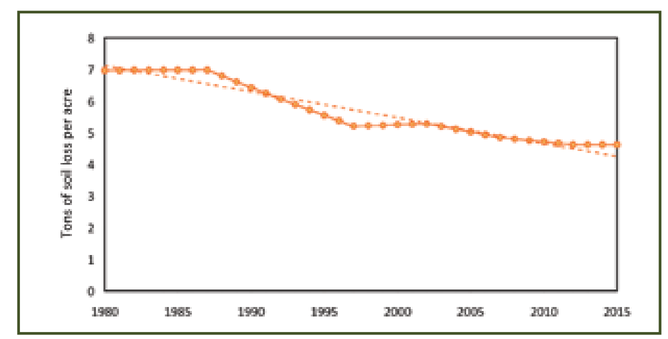


Figure 1.88. Soil Conservation indicator for wheat.

Soil Conservation Indicator

The Soil Conservation indicator decreased 40 percent, from more than 7 tons per acre in 1980 to 4.62 tons per acre in 2015. While the average trend since 1980 shows significant improvement in per-acre soil erosion, these improvements occurred primarily before the mid-1990s. Adoption of conservation tillage practices for wheat have increased since the mid-1990s, with roughly 20 percent in reduced or no-till in 1985 increasing to close to 60 percent of wheat acreage in reduced or no-till in 2015.

Irrigation Water Use Indicator

Wheat improved (decreased) its volume per incremental bushel produced as a result of irrigation by 26 percent. Incidence of irrigation for wheat is relatively low and has not changed significantly over time; 4 percent of wheat acreage was irrigated in 1980, and 6 percent of wheat acreage was irrigated in 2015; a majority of irrigated wheat occurs in the Pacific Northwest.

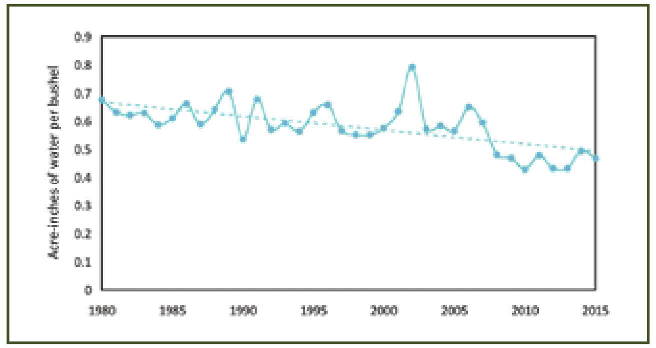


Figure 1.89. Irrigation Water Use indicator for wheat.

Energy Use Indicator

The Energy Use indicator improved (decreased) over the study period, corresponding primarily with productivity gains; energy use per bushel was approximately 81,568 BTU per bushel in 2015 compared with 101,575 BTU per bushel in 1980. There has been substantial variation in the trend over time, with high levels of energy use in the late 1980s as well as the early 2000s (Figure 1.90).

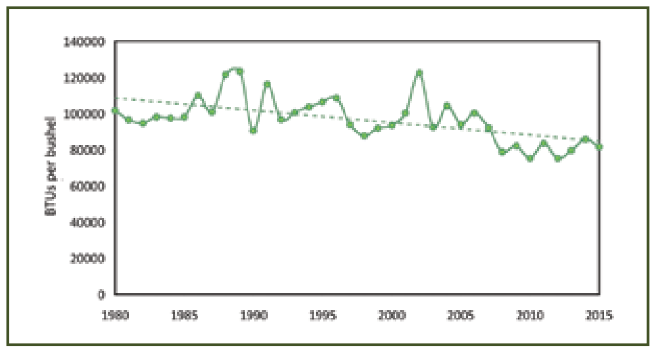


Figure 1.90. Energy Use indicator for wheat.

Greenhouse Gas Emissions Indicator

The Greenhouse Gas Emissions indicator does not show a consistent trend over the study period, with substantial variation throughout the study period. Emissions were approximately 22 pounds of CO_2e per bushel in 2015, compared with 23 pounds of CO_2e per bushel in 1980.

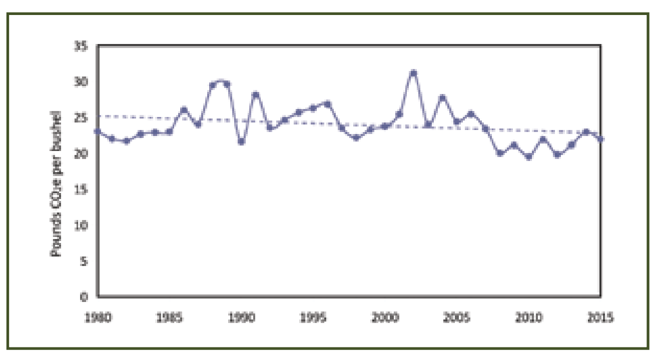


Figure 1.91. Greenhouse Gas Emissions indicator for wheat.

DISCUSSION AND CONCLUSIONS

This section explores broad-scale, commodity-level progress on key indicators of sustainability over time related to the major challenges facing agriculture in the 21st century: increasing demand and limited resources. The five key indicators explored here focus on efficiency of resource use as tied to production. Additional information is included in Appendix B that illustrates the total resource use and the per-acre resource use for each crop, utilizing the indicators explored here.

Over the 36-year period of analysis, all crops demonstrated progress in most of the environmental indicators; however, significant variation in trends over time exists, and trends in the most recent five to 10 years identify opportunities for improvement. Improvements in efficiency were driven, at least in part, by improvements in yield for all crops. However, considering the increase in overall production and area, the total resource use is increasing in most cases as well (See Appendix B). Importantly, the analysis here also indicated for which crops and indicators the improvements have stopped or reversed in recent years. While trends due to transient climate events, such as droughts in 1988 or 2012, appear in the trends analyses, these cause interruptions in the long-term trend rather than changes in direction. While climate events are regional in character, so is the geography of crop production, and specific events influenced crops differently based on their locations; for example, most crops show some negative impact on yield due to the extensive 1988 drought, but crops grown across the northern tier of the country, such as wheat and barley, were more affected.

In contrast to climate-induced events, changes over time that are tied to technological progress are often stepwise, rather than continuously linear. As new practices and products are developed and widely adopted, additional improvements should be achievable. For example, improvement (reduction) in the Soil Conservation indicator in particular has slowed or stopped for many crops in recent years. The increasing adoption of cover crops and focus on soil health-enhancing conservation practices could potentially begin to turn another corner on soil erosion to achieve reductions.

We focus on national-level trends in order to provide an assessment of the aggregate impact of U.S. commodity agriculture. However, agriculture is highly variable across the country due to combinations of environmental, historical, and social factors, and specific local or regional results may diverge from these national trends. By advancing environmental outcomes and providing a science-based approach to understanding and measuring sustainability indicators, this report represents a starting place for discussion of continuous improvement opportunities and provides guidance for future research objectives that can help drive long-term trends and lead to better understanding of the factors influencing them.

DATA GAPS AND RESEARCH OPPORTUNITIES

The five indicators explored here begin to illustrate the scope of environmental sustainability of crop production over time, in a limited context. We recognize that other sustainability concerns, considered in Part Two, and socioeconomic considerations, considered in Part Three, are also critical to understanding the overall environmental impact of agriculture in the U.S. In developing the indicators presented here, we also note areas where limitations in the analysis or in available data limit the broader interpretation of the results.

We consider each crop separately; in reality, very little land is in continuous production of any one of these crops. Rather, land managers use rotations and diversify what is grown on any one plot of land year by year. The crop-specific analysis provides important and useful information for commodity sectors and for supply chain analysis; however, the overall sustainability of U.S. agriculture must be considered in a multi-crop context. In particular, crop rotations, not just individual crops, can influence the indicators presented here.

One limitation of the indicators presented here is that they inherently account for land cover change; that is, while we present the total acres planted to a crop, those acres may be located in different parts of the country in different years. In Part Two we explore more how trends in shifting land cover can be better accounted for.

At the national scale, the main drivers of the changes observed here can be articulated. Crop production and management respond to changes in underlying economic conditions, such as crop prices, weather conditions, and technological change in available inputs and equipment. While some of these drivers respond to drivers at the national level (e.g., in national agricultural policies), others, such as weather conditions, can have a local or regional impact. Agriculture is a complex enterprise, and analysis of context and drivers is equally complex.

PART TWO: National Trends in Land Use and Management

BIODIVERSITY AND LAND COVER CHANGE

Biodiversity is a critical consideration for understanding agricultural sustainability; how lands are managed determines the extent and quality of available habitat and population health for flora and fauna. The Millennium Ecosystem Assessment identified land cover change and habitat transformation from natural ecosystems to agriculture as a major direct driver of biodiversity loss [63]. Over the past several years, Field to Market has been pilot-testing a farm-scale Biodiversity metric, the Habitat Potential Index (HPI). The availability of lands in natural vegetation, such as grasslands, forestlands, and wetlands, is an important indicator of the ability of a region to support a diverse ecosystem of flora and fauna. The habitat metric is the only one in the Field to Market program that considers a spatial area larger than a single field. The HPI quantifies farm-level habitat and landscape change from year to year and was developed in response to sustainability concerns regarding wildlife resident on and migrating through farmlands, and on-farm flora diversity and protection of sensitive ecosystems such as wetlands. Cultivated farmland disrupts natural ecosystems, but land management practices that preserve certain important buffers of native perennial grasses or trees, and target specific flora and fauna species can be used to provide habitat to maintain biodiversity.

Biodiversity and habitat potential are inherently local and challenging to assess at the macro scale. In addition, there is a wide diversity in management practices that influence habitat potential, and we currently do not have nationally available aggregate data that allow trends in such management to be tracked. However, one important consideration for maintaining and enhancing habitat at a regional and national scale that can be evaluated is the extent of change in land cover, in particular in assessing land cover change as it relates to cropland. For this report, we therefore include a discussion on land cover change trends between cropland and natural vegetation land cover classes as a proxy for consideration of the quantity and quality of habitat that can support a diverse ecosystem. Land cover change refers to changes in vegetation on a particular piece of land such as conversion of land between cropped and non-cropped systems, with a focus on lands used for production of the commodity crops in the Field to Market program. This section is intended to address the Field to Market goal to advocate for a research agenda to inform the ability of U.S. agriculture to achieve "conservation of native habitat, enhancement of landscape quality, and improvement of conservation outcomes." While we recognize that land cover is an imperfect proxy for assessing native habitat, the available information nevertheless allows us to begin including this important sustainability consideration in the conversation about national-level trends in sustainable agriculture.

Field to Market's Biodiversity Metric

The Biodiversity metric is an educational tool that identifies opportunities for growers to optimize ecological benefits of land management and effective stewardship based on the land cover(s) present on their farm. Biodiversity under the HPI includes a variety of native species and ecosystems that may be found on or near the farm—plants, invertebrates, birds, mammals, reptiles and amphibians, and fish. The HPI considers current land cover types present at the farm scale—including production lands and non-production lands—as well as the producer's management activities for each land cover type. Land cover types include crop production areas, forest, grasslands and savannas, wetlands, surface waters, and edge-of-field areas such as buffer strips. The approach is intended to promote protection and enhancement of existing on-farm habitat attributes by emphasizing the ecological benefits afforded by effective stewardship of all land. By design, best management practices and sound environmental stewardship incorporate relevant ecosystem services, including biodiversity. The HPI was developed specifically for Field to Market, and will be fully documented and integrated into the online metrics platform in 2017.

Land Cover Trends in the United States

At a regional and national scale, understanding the major trends and drivers for land cover change in agricultural regions helps to illuminate the aggregate challenges and opportunities for addressing concerns about habitat potential and landscape quality. Recent efforts to synthesize the information from satellite imagery on land cover in the U.S. now make it possible to examine trends over time on a spatially explicit basis rather than a simple statistical basis. Prior to development of these data products, it was only possible to compare statistics within a county, state, or region to understand which land cover or crop areas might be increasing or decreasing. Satellite analysis enables the next step—determining which land cover types were converted into other types. Thus, for purposes of this report, we can evaluate where cropland expanded or contracted, what land types were converted to crops, and what land types replaced cropland taken out of production. These land conversions are important for understanding additional aspects of sustainability such as soil carbon change.

There are two main sources of information for this section—the Land Cover Trends reports released by the U.S. Geological Survey (USGS) that reach back to the beginning of the satellite era and characterize land cover from 1973 to 2000 [64-67], and the USDA Cropland Data Layer (CDL) product that was developed in the early 2000s and is available for all states from 2008 to the present [68]. One key difference is that the earlier land cover trends analysis categorizes only major land cover types, and thus treats all agricultural land as one category. Advances in imagery resolution and processing techniques have enabled the development of the crop- and rotation-specific maps based on the CDL, available since the beginning of the 2000s. There remains substantial uncertainty associated with these estimates of land cover change; in particular, the confidence is lower for areas on the margin of agricultural areas where switching between crops and other land cover may occur more frequently. While no comprehensive national government-led study has been conducted with the CDL, substantial literature specific to cropland use trends will be discussed in the second half of this section.

Agricultural Land Conversion from 1980 to 2000

Spatial maps of land cover change based on satellite data have been developed over the past several decades. As imagery becomes more highly resolved, and methods for processing raw imagery into specific vegetation types become more advanced, maps of greater spatial resolution and ecosystem specificity are becoming available. Recently, the USGS has led a multi-agency effort to assess the satellite-derived land cover change over the U.S. from 1980 to 2000. They have produced four Land Trends reports based on major ecoregions in the U.S.—Western, Midwest-South Central, Great Plains, and Eastern [64-67]. These reports provide a view of the historical change and major drivers of change in land cover, illuminating large-scale transitions that affected agricultural land use during this 20-year period. The analysis includes major land cover types that are critical for biodiversity, such as wetlands, and also illuminates trends toward urban development that reduce the amount of land available for native habitat.

The primary data were derived from Landsat satellite imagery from multiple generations of instruments, and are available in the Landsat data archive, supplemented with aerial photography where necessary and available. The primary data points for comparison of change were 1973, 1980, 1986, 1992, and 2000. Here we focus on results from 1980 to 2000, corresponding to the time period for environmental trends in the indicators described in Part One. The land cover changes were determined using a statistical sampling approach, manual classification of land cover, and comparisons of land cover over five different study dates. Land cover was determined as belonging to one of 11 classes: water, developed, mechanically disturbed, mining, barren, forest, grassland/shrubland, agriculture, wetland, non-mechanically disturbed, and ice/snow [69].

Here we present data from these reports and summarize trends (K. Sayler, personal communication), in particular as they relate to the agricultural land category, for three of the time periods for which the analysis is available—1980–1986, 1986–1992, and 1992–2000. While this data includes commodity croplands that are the focus of this report, it also includes other extensive agricultural lands, such as pasture for grazing. Thus our purpose is to illuminate broad-scale trends for all agricultural lands, since specific trends for any one crop cannot be determined from this information. At the national level (Figure 2.1), there is a clear trend over the 20-year period of agricultural land lost to developed land, and to grass or shrubland and forest land in the latter two time periods. It is important to note that a significant portion of agricultural land moving to grassland is driven by the Conservation Reserve Program, and that this is generally not a permanent shift; rather, CRP-enrolled land may be brought back into agricultural production in certain economic environments.

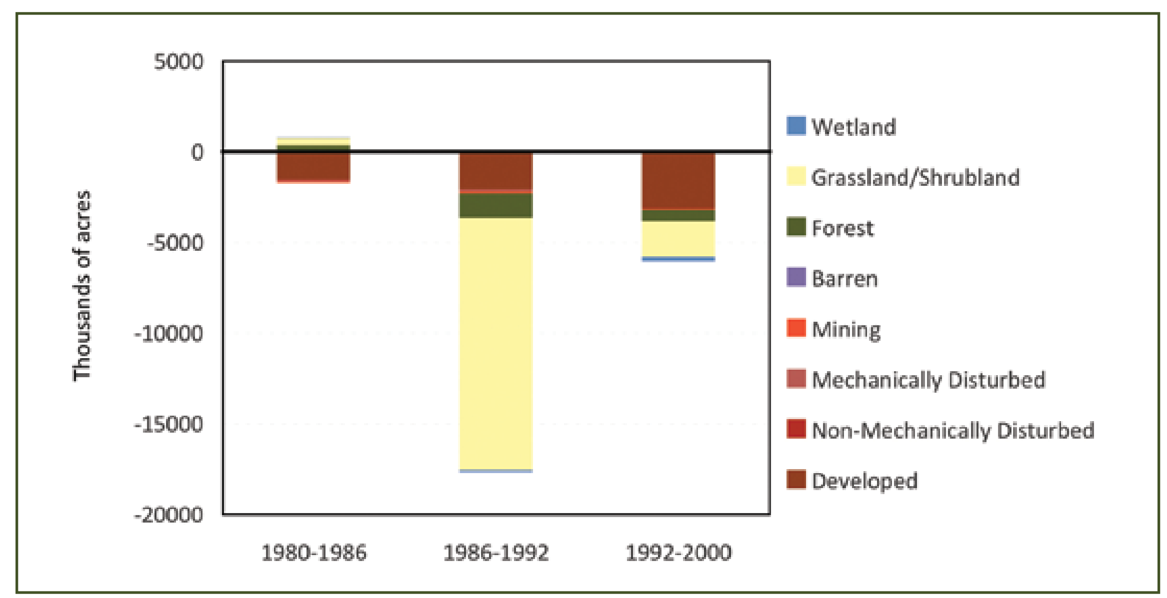


Figure 2.1. Aggregate national change in agricultural land; expansion (positive) and contraction (negative) in acres for three time periods from 1980 to 2000.

Land Conversion in the Midwest – South Central U.S.

In this region, composed roughly of the Upper and Lower Mississippi and Ohio River Basins (but excluding the Missouri and Tennessee basins), agriculture represented 42 percent of all land area in 2000 [63]. Large-scale trends across this time period and region include overall loss of agricultural land of 2.7 million acres (0.9 percent) between 1973 and 2000, with the greatest rate of change from 1992 to 2000. Agricultural land was lost to developed areas, but agricultural land was also gained, primarily from forest and grassland conversion. The conversion of agricultural land to developed land, particularly around large cities such as Chicago, Indianapolis, and Minneapolis-St. Paul, was the largest single trend in land use in this region over the time period. Agricultural land also increased, particularly in the South Central region (Ozark Highlands), where the dominant trend was conversion of forestland to agriculture, particularly in the early part of the period (1973–1980) [66].

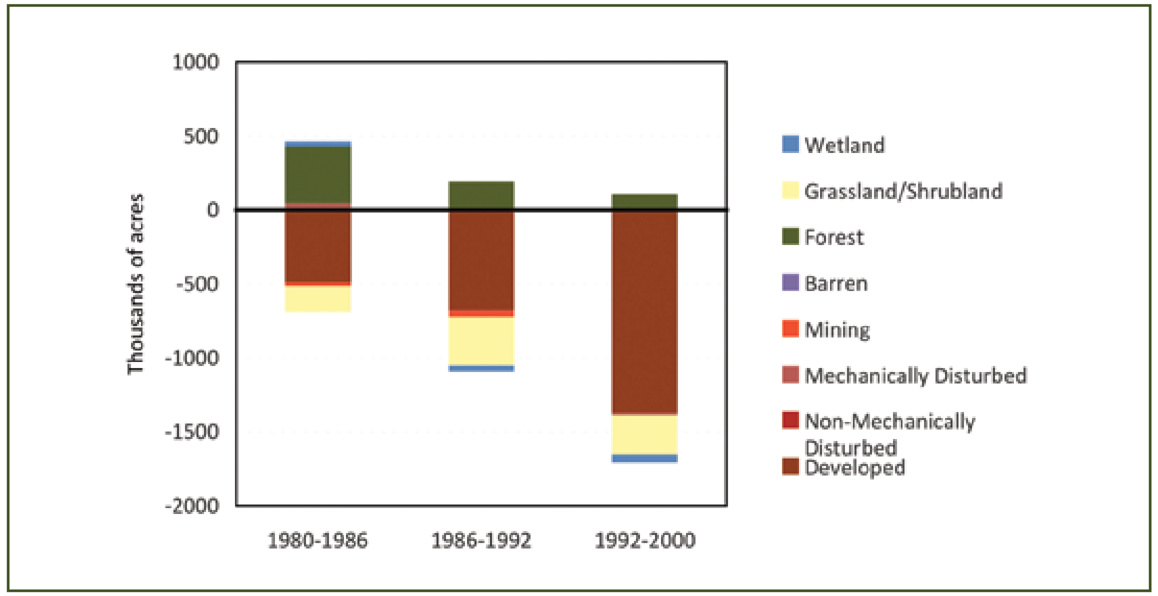


Figure 2.2. Aggregate change in agricultural land in the Midwest–South Central United States; expansion (positive) and contraction (negative) in acres for three time periods from 1980 to 2000.(negative) in acres for three time periods from 1980 to 2000.

PART TWO: NATIONAL TRENDS IN LAND USE AND MANAGEMENT—IMPLICATIONS FOR SUSTAINABILITY

Land Conversion in the Western U.S.

This region, defined as the Rocky Mountains, desert Southwest, and West Coast, has diverse land cover with a relatively smaller proportion of land (6.5 percent) devoted to agriculture, although it contains several very important agricultural regions, including the Snake River Basin and the California Central Valley. Agricultural land in this region experienced a small net loss of 1 million acres (0.2 percent) over the 1973–2000 period, driven by conversion to developed land. In this region, there was an increase in agricultural land in the early 1980s, primarily conversion from grassland. Over time, some agricultural land has also been lost to developed land. However, in this region the most common land type both converted to and converted from agriculture was grassland. Much of the conversion of agriculture to grassland in the latter part of this period is attributed to participation in the Conservation Reserve Program [64].

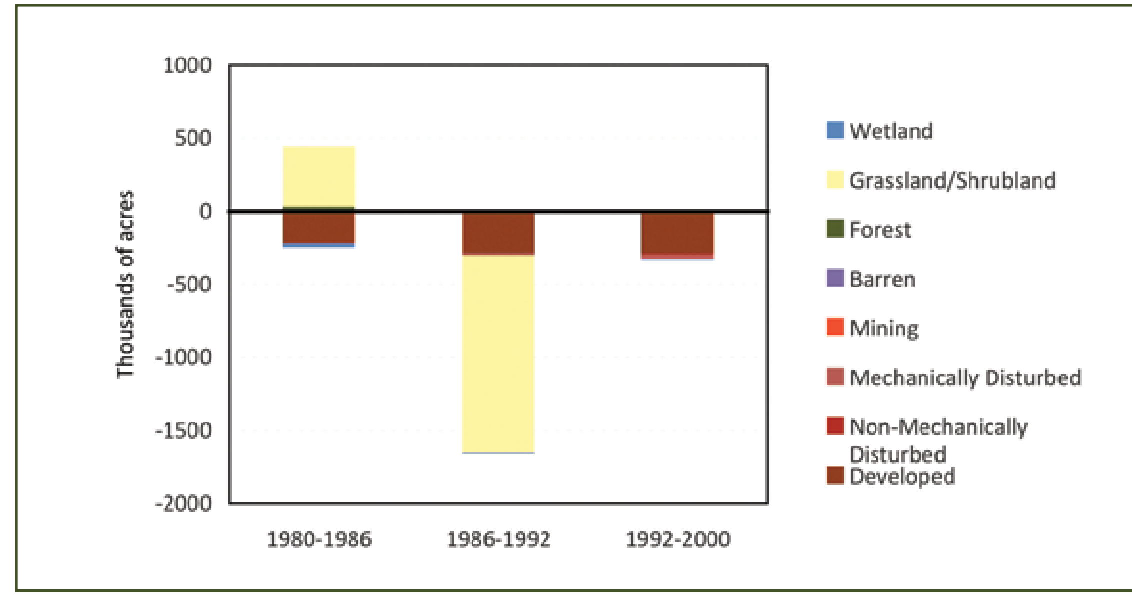


Figure 2.3. Aggregate change in agricultural land in the Western U.S.; expansion (positive) and contraction (negative) in acres for three time periods from 1980-2000. (negative) in acres for three time periods from 1980 to 2000.

Land Conversion in the Eastern U.S.

This region, comprising the eastern seaboard, Tennessee River Basin and Gulf states from Mississippi east, has experienced a decline in agricultural land area, from 23.1 percent in 1973 to 21.6 percent in 2000. Agricultural land was lost throughout the period, with relatively little change between 1973 and 1980 and the greatest rate of change in the 1986–1992 period. Overall, 6.2 million acres of agricultural land was converted to other land cover types. Depending on location, agricultural land was lost to both developed land and to forestland [67].

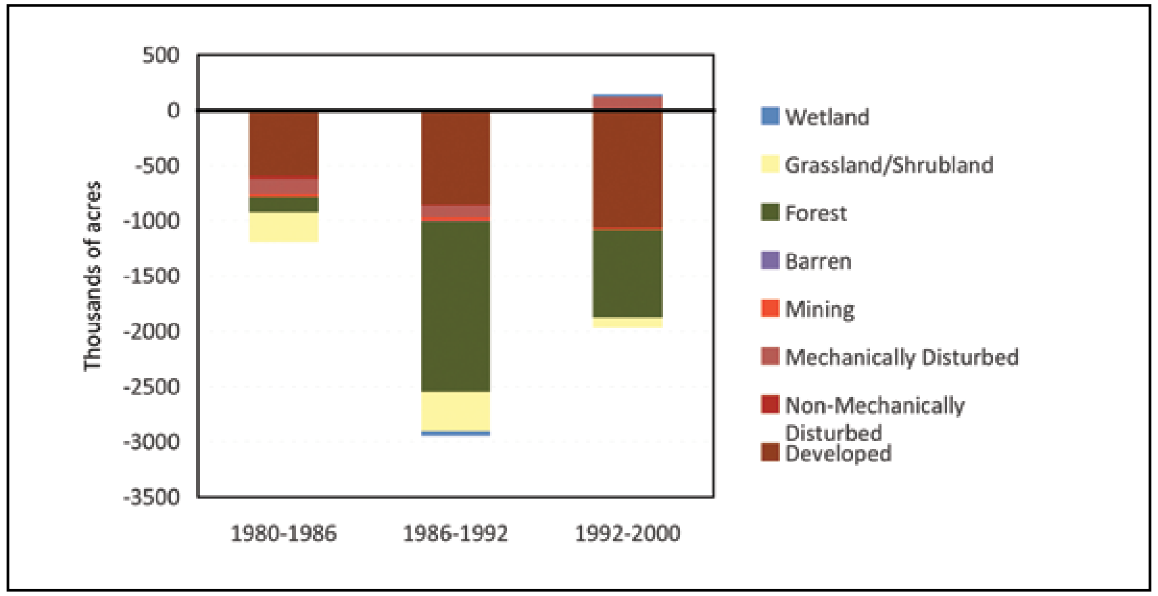


Figure 2.4. Aggregate change in agricultural land in the Eastern U.S.; expansion (positive) and contraction (negative) in acres for three time periods from 1980 to 2000.

PART TWO: NATIONAL TRENDS IN LAND USE AND MANAGEMENT—IMPLICATIONS FOR SUSTAINABILITY

Land Conversion in the Great Plains

The Great Plains region comprises a large area of land between the Mississippi and the Rockies and is an area with a large proportion of grassland and agricultural lands. Agriculture comprised 46 percent of the land area in 1973, which declined to 43.8 percent by 2000, a net loss of 11.9 million acres of land. Agricultural land actually increased early in the period—from 1973 to 1980—and then slowed, finally reversing with conversion back to grassland after 1986 in response to the Conservation Reserve Program [65].

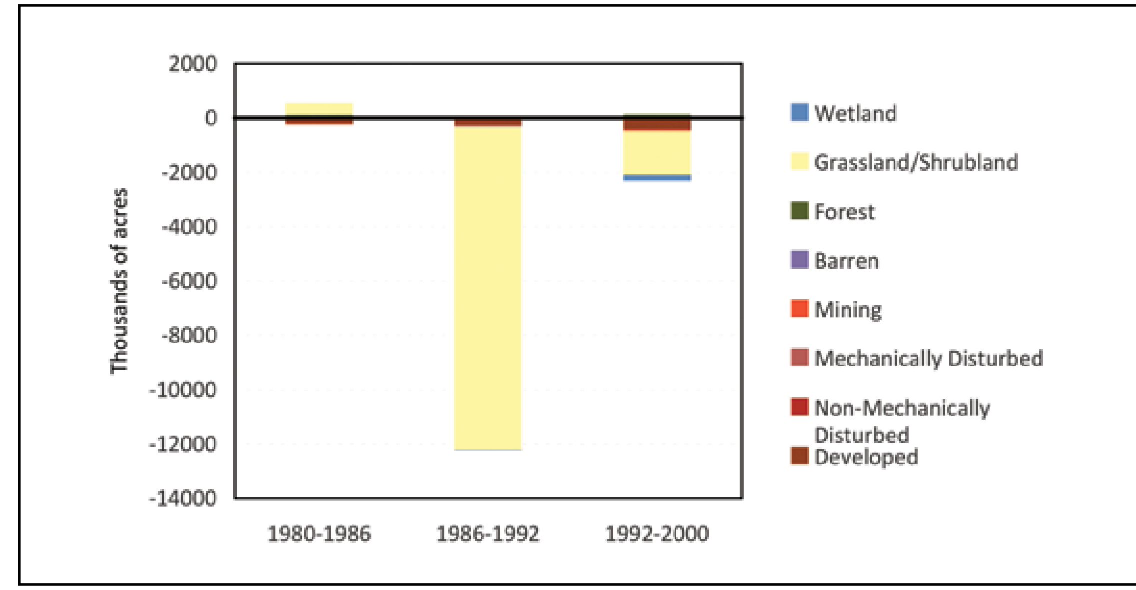


Figure 2.5. Aggregate change in agricultural land in the Great Plains; expansion (positive) and contraction (negative) in acres for three time periods from 1980 to 2000.

Agricultural Land Cover from 2000 to 2015

The remote sensing data products that underlie the USGS Land Cover Trends reports continue to be produced and may be incorporated into future assessments that include agricultural land in aggregate. Advances in remote sensing technology and in the science of interpreting satellite data have also enabled the production of new data products. For U.S. agriculture, one of the most relevant is the Cropland Data Layer, developed by USDA in collaboration with NASA (National Aeronautics and Space Administration). Development of the CDL began in the late 1990s in some locations. While some coverage of states is available for years in the early 2000s, the CDL has only been available for all states since 2008.

The CDL is the first product to discern specific crops at high spatial resolution for the U.S. There are now eight complete years of CDL information for the U.S., and these data are the source for land use change analysis and publications. Notably, the methodology for developing and analyzing the CDL product remains a topic of active discussion in the scientific community. The row crop analyses have been found to have an accuracy of 85–95 percent, but research continues to describe and refine the analyses. In particular, there is higher confidence in the land cover designations from the CDL in regions with large proportions of cropland, and less confidence in areas where agriculture is marginal and plots of land may shift in and out of production more frequently. While the national-level data are available from USDA through the CropScape web portal, no summary analysis report has been produced with the information [68].

Our purpose in this section is to introduce some of the key findings of recent literature using the CDL in order to explore more recent drivers and trends in cropland change. Studies discussed here largely use the CDL for regional rather than national analyses. However, by beginning to assess these studies, we can gain some understanding as to recent trends in spatial patterns of agriculture-driven land use change, such as conversion in or out of crops and changes in rotation patterns.

The CDL has been extensively evaluated for accuracy over the course of its development. Researchers have found that the highest confidence in the crop-level land classifications is for regions that have a high density of cropland; where cropland is less prevalent, overall accuracy can be lower. Thus, many of the studies discussing trends in cropland change have focused on highly agricultural areas. The changes that can be detected over time with the CDL include conversion between actively cropped lands and non-cropland, such as grasslands, pasture lands, or idle cropland (e.g., CRP), as well as changes in rotational frequency. As the CDL record is extended in future years, additional multi-year analyses will be able to discern trends over time.

Findings from six analyses published in the peer-reviewed literature that used the CDL to identify agricultural land cover change over large regions (e.g., multiple states) are summarized in Table 2.1. Each study is different in terms of the spatial extent covered, and the time period and cropping systems of focus. However, there are some common trends in the findings that emerge. In general, over the time frame of 2008–2012, the studies found an increase in cropland [70, 71, 72, 73]. More specific trends that were observed were increases in land in corn and soybeans, and decreases in rotational complexity. Analyses found that these increases in cropland were associated with declines in grasslands of all categories [74]. These changes correspond to a time period of higher commodity prices that incentivized greater crop production. Two specific trends are of importance to biodiversity. Some of the grassland converted to cropland can be attributed to land formerly enrolled in the CR) being brought back into production, indicating loss of habitat adjacent to existing farms. Second, conversion of grasslands located near wetlands may have a disproportionate impact on habitat potential of surrounding area, beyond just the acres directly converted [74]. One study explicitly ties the change over time in land use for annual crops to the concept of intact habitat for wildlife, and finds that such lands declined over the 2009–2013 period [75].

Reference	Spatial Domain	Cropland Data Layer— Years of Analysis	Cropland Change Patterns Identified
Johnston, 2014 [70]	Dakota Prairie Pothole Region	2006–2012	Corn/soy increase 27 percent in Dakota Prairie Pothole from 2010 to 2012;decrease in both small grains and non-native grassland.
Lark et al., 2015 [71]	Contiguous United States	2008–2012	Net cropland increase from 2008 to 2012. Grasslands were source of 77 percent of all new croplands; corn, soy, and wheat all increased in the new croplands.
Mladenoff et al., 2016 [72]	MN, WI, MI	2008–2013	37 percent (>800k ha) of non-agricultural open land converted to agriculture, with corn and soybeans as dominant new land uses.
Plourde et al., 2013 [73]	9 states (AR, IL, IN, IA, MS, MO, NE, ND, WI)	2003–2010	Reduction in rotation diversity;corn increase observed beginning around 2007.
Wright & Wimberly, 2013 [74]	5 states (ND, SD, NE, MN, IA)	2006–2011	Net decline in grass-dominated land cover of ~530,000 ha; analysis for proximity of grassland conversion to wetlands.
Gage et al., 2016 [75]	Great Plains	2009–2013	Identify lands not in cropland over study period; find that both forest and grassland decline.

Table 2.1: Summary of research applying analysis of the Cropland Data Layer to identification and understanding of land use trends.

Studies that identify land cover trends over large regions represent just one component of the scientific literature on the CDL, which includes extensive documentation of methodologies for working with the coverages as well as assessments of the accuracy of the data product. These have found that in general the accuracy is greater for regions of more cropland [78], and thus varies somewhat by region of the country, with a greater degree of accuracy in the eastern part of the country than in the northwest [77]. Ongoing comparisons of the CDL to long-term statistics from the National Agricultural Statistics Service (NASS) have found that the estimates of agricultural land can be underestimated [78] for soybeans in particular [76]. More detail on the sources of uncertainty and comparison to other remote sensing products can be found in the literature [78, 79].

Summary

Over the time period of 1980–2015, the extent of agricultural land across the U.S. changed, and the specific patterns of land cover change varied over time and space. Remote sensing data can help to identify large-scale trends that may not be obvious from statistics and survey data alone. In aggregate, the data presented here point to increases in overall cropland in the early 1980s, followed by a loss of cropland in the 1990s to urban areas and grasslands, and finally, recent information indicates a new expansion of cropland in the years since 2008 at the expense primarily of grasslands. While these aggregate trends have diverse drivers, an important consideration is economic environment, including crop prices, as well as available subsidies or incentives for land management. For example, the increase in cropland area since the early 2000s can be somewhat attributed to the emergence of biofuel policies, which have increased the market for certain agricultural products, as well as to the reduction in CRP resources to encourage conservation set-aside land. In just the past two years, low commodity prices have already increased interest in greater enrollment in CRP.

By considering published data on land conversion, rather than simple acres in crop as reported in Part One, we can begin to assess how land cover change may influence the availability of specific land types for native habitat to support diverse ecosystems. While we have incorporated here two important resources, there remain gaps in the time period and completeness of the trends. This section highlights the emerging potential of remote sensing data to track trends in specific land cover and even land management over time. Considering the overall patterns of change and the economic context for agriculture during the same time periods highlights the adaptive responses of landowners and managers to remain economically sustainable. Thus better understanding of these trends can help in future design of both government policies and programs that support agriculture, as well as supply chain programs that can influence these trends through economic signals. In Part Three of this report, we further explore the social and economic indicators of farm sustainability in the U.S.

SOIL CARBON

Soils are the largest organic carbon pool on the land surface, and agricultural soils that have been cultivated for many years often have substantial opportunity to increase soil carbon through management change. Agricultural practices that have shown potential to lead to increases in soil carbon over time include reducing soil disturbance through conservation tillage; adopting crop rotations that incorporate higher biomass crops; adopting practices that increase residue retention; and avoiding fallow periods by implementing cover crops [80]. Carbon accumulation in the soil is difficult to measure because it occurs over long time periods and follows a nonlinear trend. While initial change may be rapid, a decrease in accumulation rate can occur due to reaching an ecosystem equilibrium, or steady state [80]. For example, after conversion from a conventional tillage to a continuous no-tillage system, a field may approach a new equilibrium after 15–20 years, with the largest sequestration rates occurring between five and 10 years [81]. In some instances, soils that are cultivated continuously do not experience increases in soil carbon even with adoption of no-till practices [82, 83, 84]. Thus, soil testing for monitoring change and identification of appropriate management techniques is essential if the objective is to build soil organic matter on cultivated land.

The Field to Market goals statement identifies two specific considerations for soil carbon—one is that soil carbon enhancements can contribute to reductions in overall net greenhouse gas emissions, and the second is that soil carbon is a key indicator of soil health. For sustainable production, stewardship of and improvements to soil carbon can reduce the net contribution of a field to greenhouse gases as well as improve long-term sustainability and resilience of the land by enhancing soil health. Field to Market produced a separate report on soil health that details how our current metrics program considers and will respond to management efforts on farm to improve soil health [15].

Our current Soil Carbon metric applies the USDA NRCS Soil Conditioning Index, a qualitative directional conservation planning tool designed for use on individual farms. While applying this index has value for the goals of the metrics program, the methodology is not extensible to a national-level indicator in the same manner as the metrics and indicators considered in Part One of this report. Therefore, in order to provide an assessment of trends over time in soil carbon at a national level, we turn to a nationwide modeling study of soil carbon that is conducted for the national Greenhouse Gas Inventory. The U.S. government is required, as a party to the United Nations Framework Convention on Climate Change, to report annually on greenhouse gas sources and sinks from all sectors [28]. Trends from this inventory approach are available from 1990 through 2007 and are presented here by major cropping system.

Field to Market's Soil Carbon Metric

For field-level assessment of soil carbon, Field to Market has adopted the Soil Conditioning Index (SCI), a conservation planning tool developed by USDA NRCS to provide guidance to users on probable directional change in soil carbon as a result of changes in tillage and residue management practices. SCI is calculated from the Revised Universal Soil Loss Equation 2 (RUSLE2) and is a unitless, relative, and crop-specific measure with an output range of +1 to -1. Very small values (+/- 0.05) represent index levels where there is little or no confidence that soil carbon is changing in either direction. As the SCI value moves further away from zero, it indicates greater confidence that the soil carbon is changing; therefore, higher values indicate greater confidence that soil carbon is increasing. The SCI has three main components—soil organic matter (SOM), field operations, and erosion. SOM generally contains approximately 58 percent carbon, and therefore the SCI provides an acceptable proxy for inferring directional change in soil organic carbon.

By adopting this metric, we enable producers and Fieldprint® Project managers to engage in meaningful discussions about the importance of soil carbon and the likely trend occurring on fields. This leads to guidance on how to improve on sustainability performance for this metric, and provides a measure that can be tracked over time, allowing producers to monitor their performance. While this metric provides important guidance and establishes Soil Carbon as a key sustainability metric to track, it is not a value that can be replicated at the national scale. Field to Market continues to explore options to adopt a more quantitative model of soil carbon into the metrics program.

National Soil Carbon Estimates, 1990–2007

In order to estimate carbon stock changes in agricultural soils from 1993 to 2007 for the USDA Agriculture and Forestry Greenhouse Gas Inventory, more than 400,000 National Resources Inventory survey points were used to represent a statistical sampling of land use and management practices on all non-federal lands in the U.S. [85]. Although soil carbon for both mineral and organic soils is included in the inventory, here we include only mineral soils, which represent the vast majority of U.S. commodity crops. It is important to note that organic soils, while small in area, are very vulnerable to soil carbon loss when cultivated for crop production.

Simulation of change in soil carbon is dependent on many factors, including land management, weather conditions, soil characteristics, and land use history. Soil carbon change for crops was not calculated on a crop-by-crop basis, as the simulations require multiple years of land management and are sensitive to land use history. Therefore, the results are reported as five-year averages for a cropping system, which may include multi-crop rotations. Calculation of carbon flux for alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat were calculated by the DayCent model.

The analysis defined 10 major cropping systems based on five-year rotations as determined by the NRI survey data [32]. Six of the rotation groups contain results for the commodity crops considered in this report, and we include two additional categories—hay and CRP lands—that represent long-term rotation options often employed by commodity farmers. The cropping systems included in this report are:

- **Row crops:** At least three of five years in corn, soybeans, and/or sorghum
- **Small grains:** At least three of five years in barley, wheat, and/or oats
- **Low-residue crops:** At least three of five years in cotton, potatoes, sugar beets, dry beans, onions, and/or tomatoes
- **Hay (legume):** Five continuous years in legume hay
- **Flooded rice:** At least three of five years in flooded rice production
- **Other:** Agricultural lands that did not have three out of five years in any of the other definitions; contains a mix of crops and diverse rotations
- **CRP:** Land enrolled in the Conservation Reserve Program as grassland for three of five years

DayCent is a comprehensive ecosystem model that simulates plant-soil nutrient cycling by representing key processes occurring in the soil, including plant growth, senescence of biomass, decomposition of dead plant matter and SOM, and mineralization of nitrogen [86, 87]. To calculate carbon flux, the model was parameterized using various land uses and land management scenarios based on historical statistics. Three sets of simulations were performed to assess the soil's capacity for the loss/gain of carbon: the pre-settlement native vegetation, the historical cropping management pattern obtained from various historical sources, and the modern cropping management system obtained from analysis of NASS, ERS, and NRCS statistical and survey records. Simulations were conducted until 2013, but results are included only up to 2007 because that was the last year that land use data were available. Five-year annual means are reported because carbon fluxes during any given year are dependent on previous land use; hence changes in management and cropping system over time are captured in the individual simulations.

Modeling a complex system like soil carbon flux involves many different data requirements, and representation of complex biophysical processes means that it is important to also assess the level of confidence and reliability of the results through an uncertainty analysis. The USDA GHG inventory's uncertainty assessment of input data and the model concluded that major crops grown on mineral soils sequestered 92.3 million pounds CO_2eq in 2008, with a 95 percent confidence interval of +/- 64 percent [85]. While this level of confidence is higher than for the alternative methods for soil carbon estimation available, it still indicates a high level of uncertainty in the estimates.

Soil Carbon Change from 1990 to 2007

The figures in this section highlight results from the national GHG inventory discussed above. Our analysis looks at the amount of net carbon sequestration per acre and the total changes in soil carbon stock over time in the contiguous U.S. for agricultural lands in seven crop groups: rice, row crop, small grain, low residue, hay legume, other, and CRP. Results are available in five-year increments for the time periods 1993–1997, 1998–2002, and 2003–2007. Additional years of simulation will be included in future versions of the inventory, providing a consistent time series of soil carbon that can be followed as an indicator of overall agricultural system sustainability in the U.S.

Figure 2.6 shows mean annual pounds of carbon dioxide equivalent sequestered in rice production per acre from 1993 to 2007, as estimated by DayCent. Carbon sequestration per acre for rice production was positive over this time period and maintained a relatively flat trend with no major changes in direction evident.

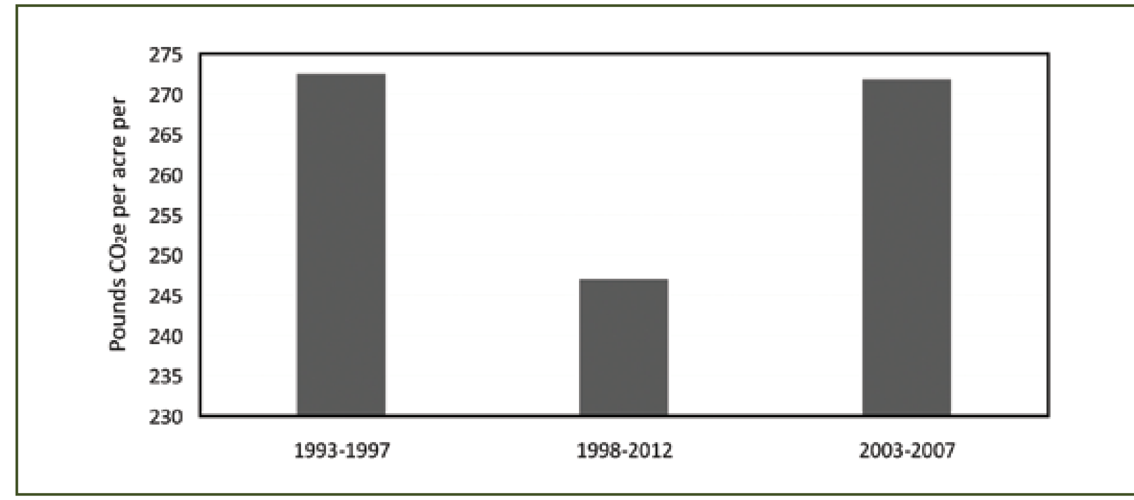


Figure 2.6: The amount of carbon (pounds CO_2e per acre per year) sequestered under flooded rice production systems.

Figure 2.7 illustrates mean annual pounds of carbon dioxide equivalent sequestered in row crops per acre, representing rotations that include corn, soybean, and sorghum from 1993 to 2007, as simulated by the DayCent model. The values for row crops are negative, meaning that, on average, they lost more carbon to the atmosphere than they sequestered. The rate of loss decreased noticeably in the 2003–2007 period, with reduction of loss by 11.4 pounds of carbon compared to the previous time period; however, the values reported here are of such a small magnitude that changes of this size would not be detectable in field-level measurements. The reduction of carbon loss per acre could potentially reflect the progress of sustainable management practices such as adoption of conservation tillage and residue management practices, which have been shown to reduce soil disturbance and increase carbon inputs to the soil through roots and residue cover [88].

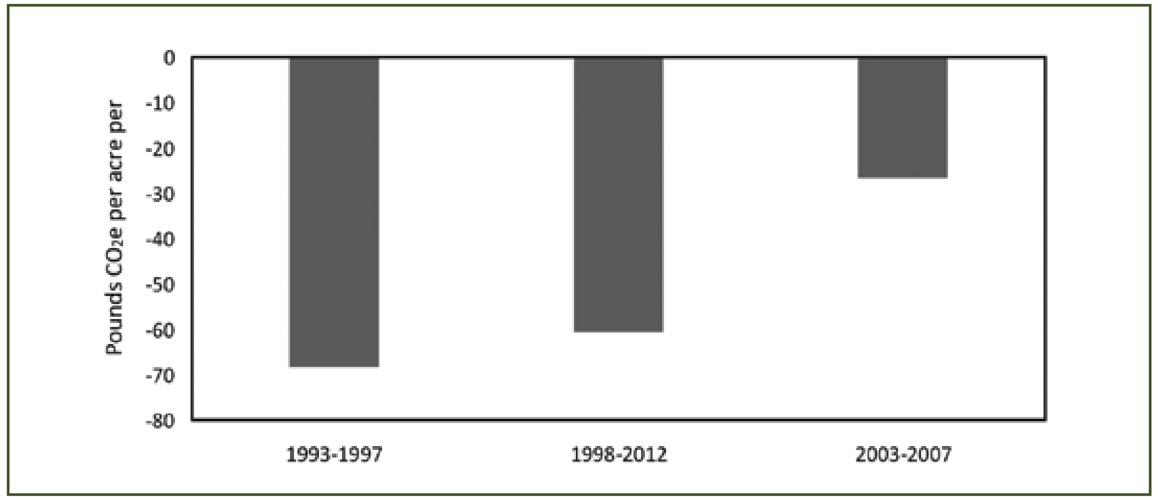


Figure 2.7: The amount of carbon (pounds CO_2e per acre per year) lost from row crop production systems.

Figure 2.8 shows mean annual pounds of carbon dioxide equivalent sequestered in small grains per acre for rotations dominated by barley, wheat, and oats. Similar to row crops, small grains decreased the rate of carbon loss per acre; however, the largest shift occurred earlier, in the 1998–2002 time period. From 1998–2002 to 2003–2007, the rate of carbon loss per acre remained relatively steady.

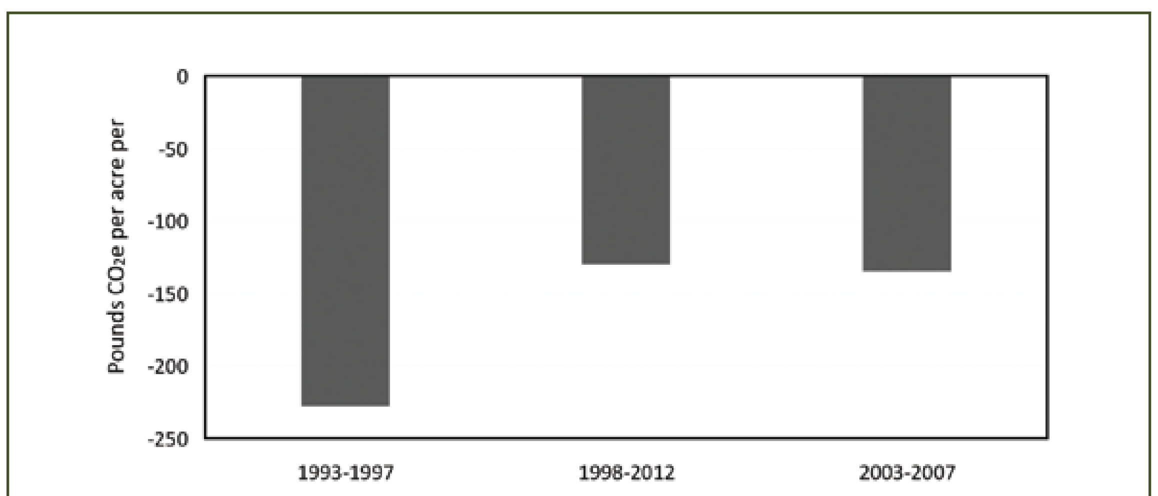


Figure 2.8: The amount of carbon (pounds CO_2e per acre per year) lost from small grain production.

PART TWO: NATIONAL TRENDS IN LAND USE AND MANAGEMENT—IMPLICATIONS FOR SUSTAINABILITY

Figure 2.9 shows mean annual pounds of carbon dioxide equivalent sequestered in low-residue crops per acre for cotton, potatoes, and sugar beets from 1993 to 2007. Low-residue crops tend to have a higher propensity to lose soil carbon due to the lower carbon input from organic material. During the time period of the study, low-residue crops lost carbon, with some variation in each time period but no consistent trend.

Figure 2.9: The amount of carbon (pounds CO_2e per acre per year) lost from low residue crop.

Figure 2.10 shows mean annual pounds of carbon dioxide equivalent sequestered in hay legume (primarily alfalfa) production per acre from 1993 to 2007. Hay legume production was a steady source of carbon sequestration due to the perennial nature of hay, which maintains continuous cover and root structure, reducing soil loss through erosion and also providing carbon input to the soil [89].

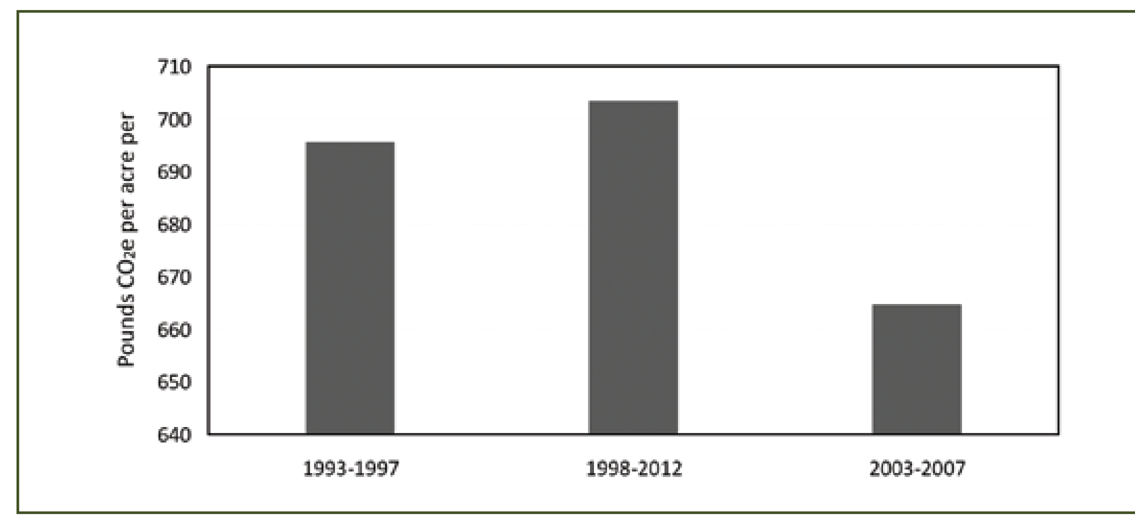


Figure 2.10: The amount of carbon (pounds CO_2e per acre per year) sequestered under hay (legume) production systems.

Figure 2.11 shows mean annual kilograms of carbon sequestered in other crops per acre for diverse rotations from 1993 to 2007. Although all years had other crops sequestering carbon, 2003–2007 saw a decrease of 35.7 pounds of carbon compared to 1998–2002. The decrease in sequestration could be a result of various elements, and this category contains a range of crops and systems, so attributing change is challenging. Nevertheless, this category is included in order to capture agricultural lands in commodity crop production as modeled in the soil carbon analysis from USDA.

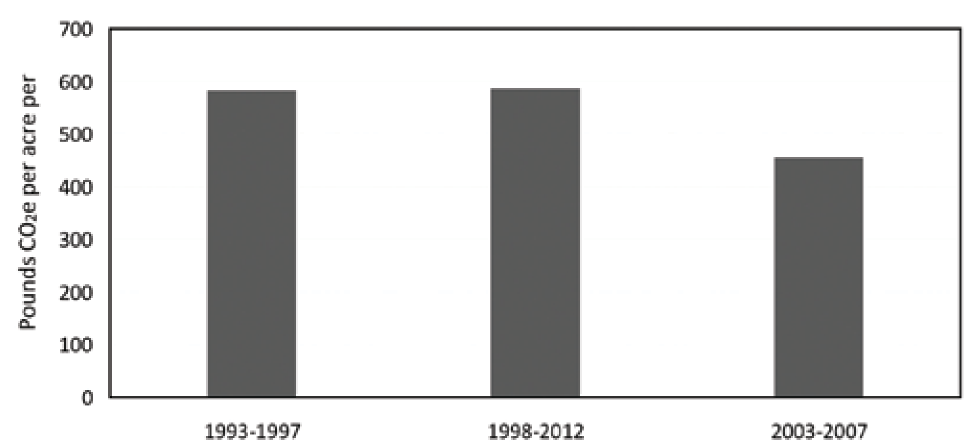


Figure 2.11: The amount of carbon (pounds CO_2e per acre per year) sequestered under other crops and complex rotation production systems.

Figure 2.12 shows mean annual pounds of carbon dioxide equivilent sequestered in land enrolled in CRP from 1993 to 2007. Land enrolled in CRP sequestered the largest amount of carbon per acre of all the crop groups. 2003–2007 sequestered an annual amount of 261 pounds of carbon per acre, which was 183.4 pounds less than 1993–1997, which could be a result of several factors. One possibility is that the land enrolled in CRP, which began in the mid-1980s, for more than 10 years may experience slowing in the rate of carbon accumulation, depending on the state of the soil when converted to grass.

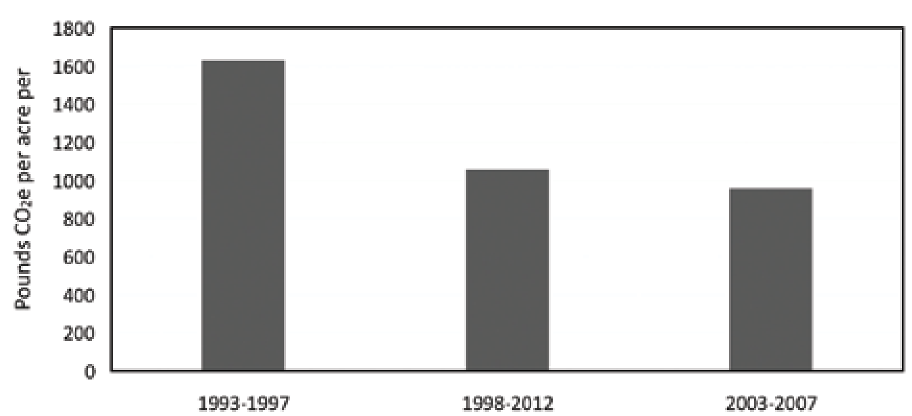


Figure 2.12: The amount of carbon (pounds CO_2e per acre per year) sequestered under land enrolled in the Conservation Reserve Program (CRP).

Figure 2.13 shows the total mean annual change in soil organic carbon measured in pounds of carbon dioxide equivalent for each of the seven crop categories reported here. Positive values from zero indicate carbon sequestration in the soil, and negative values indicate a loss of carbon from the soil to the atmosphere. Over the 14-year time period, crops sequestering carbon—including rice, hay legume, other cropland, and CRP—show a decrease in net carbon sequestration of 6.9 million pounds. Crops losing carbon to the atmosphere, including small grain, row crop, and low residue, showed an improvement (decreased loss of carbon) of 2.6 million pounds carbon. It is important to note that there are several other crop groups in the USDA's GHG inventory not included in our report. Nevertheless, this provides an indication of the trend in soil carbon from the major commodity cropping systems in the U.S. over the past two decades. Overall, losses of soil carbon have been reduced over this time period; it is important to also note that the majority of carbon sequestration occurring over this time frame is attributed to land with perennial grass cover—both hay and CRP lands—as well as the Other Cropland category, which is characterized by diverse rotations. Major row crop, small grain, and low-residue crop systems in the analysis are in aggregate serving as sources of carbon to the atmosphere, rather than sinks.

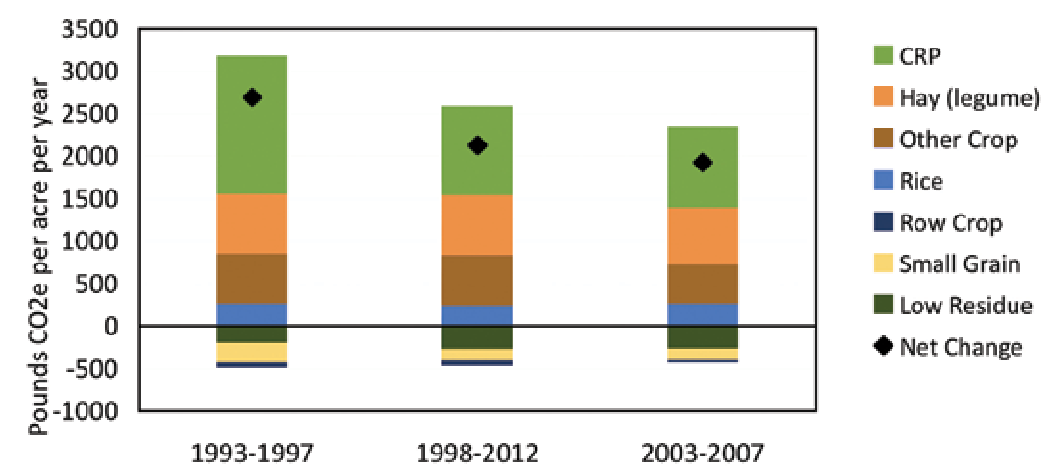


Figure 2.13: Annual soil carbon change across commodity agriculture lands in the US.

Summary

The results reported here reflect an intensive and ongoing effort by USDA to apply the best available scientific understanding and modeling approaches to assessing change in agricultural soil carbon over time. This is the first inclusion of these data in the National Indicators Report, in order for Field to Market to begin to capture this important indicator of agricultural sustainability. By considering the simulated changes over time, and with an understanding of the major factors influencing soil carbon change, these results can help inform discussions of major drivers and opportunities to reduce losses of soil carbon and to work toward enhancing soil carbon in appropriate systems.

WATER QUALITY

Water flowing over and through agricultural lands can carry to streams and groundwater sediments as well as pollutants from applications of fertilizers, manure, and crop protectants. Activities from working farms can therefore adversely affect water quality in local streams, which flow into regional watersheds. Large watersheds with extensive cropland can suffer from accumulations of nutrients and contaminants that can lead to broad-scale environmental problems. One example is the contribution of excess nutrients from farming in runoff contributing to hypoxic, or "dead," zones in large estuarine ecosystems, such as the Chesapeake Bay and the Gulf of Mexico.

Thus water quality is a key sustainability concern for agriculture; as stated in Field to Market's goals, the program aspires to deliver a *"Sustained contribution to solving regional water quality problems as evidenced by reductions in sediment, phosphorus, nitrogen, and pesticide loads from U.S. cropland."* To begin to address the need for measurement and identification of opportunities for improvement, a Water Quality metric was adopted into the Field to Market program in 2014. Water quality is complex and highly dependent on local environmental conditions and individual field management. For the metrics program, the initial tool adopted is the USDA NRCS Water Quality Index (WQI) [90].

Assessing national trends in water quality is a complex task. Field to Market's metric and approach focuses on the nutrient, sediment, and pesticide losses from individual farms fields in both surface flow (runoff) and sub-surface flow (leaching). While such outcomes can be monitored or modeled at the field level, considering the water quality in a stream or river requires understanding of a much broader range of sources as well as the fate of nutrients after they reach a stream. Here we consider two federal government programs that seek to understand trends in water quality across the nation, with a particular focus on agricultural lands. Our intention is to provide an overview of the available information and assess what can be determined about the river basin and potential improvements to water quality that may be possible at a national scale from agricultural management.

Field to Market's Water Quality Metric

The Water Quality Index (WQI) is a qualitative conservation planning tool designed for use on a single farm or field over time to evaluate conservation management influence on water quality outcomes [90]. This index was constructed by taking complex scientific information about field characteristics, soil physical factors that influence erosion, nutrient management factors, tillage management factors, pest management factors, irrigation management, and additional conservation practices and transforms them to a single, dimensionless number using specific scoring and weighting criteria. The index can be used to measure relative water quality performance of fields over time and represents those decisions that are under the direct control of a producer.

The method that yields WQI comprises three major steps. In the first step, four intermediate indexes (field sensitivity, nutrient management, tillage management, and pest management) are constructed, using weighted scores of primary factors that influence each index. Each of these indexes is influenced by several factors that can be either within or outside the farmer's control. For example, the field sensitivity index is influenced by the hydrologic soil type of the field, which is outside the farmer's control, and soil organic matter, which can be influenced by the farmer through management practices such as manure application, plant residue removal, etc. To arrive at a single number for each index, a score and a respective weight are given to each influencing factor. The sum of all weighted scores per index yields one intermediate index. In the second step, each of the intermediate indexes is then given a weight. The sum of weighted indexes produces the water quality index for agricultural runoff WQIag. In the third and final step, the index is further adjusted for the irrigation method used and the additional conservation practices. Field to Market provides additional user resources describing the use of the metric and analysis of results for fields and projects through the Fieldprint Calculator website.

WQI is considered an interim solution that allows participants in the Field to Market metrics program to begin collecting the necessary data and includes discussion of water quality concerns in sustainability objectives. Field to Market continues to work toward development of a quantitative field-scale metric that would allow for assessment of water quality impacts over larger regions.

PART TWO: NATIONAL TRENDS IN LAND USE AND MANAGEMENT—IMPLICATIONS FOR SUSTAINABILITY

National Water Quality Measurements and Trends

The U.S. Geological Survey maintains a network of water quality monitoring locations, through the National Water Information Service and the National Water Quality Assessment Program, to assess the safety of the nation's drinking water and monitor for hazards to human and aquatic systems. Site-specific in-stream, well, and groundwater monitoring information can be obtained for assessment of trends at individual locations [91]. Given the complexity of water quality, it is a highly regional concern, and in-stream observations are generally not assessed in aggregate, such as in a nationwide indicator. Different regions and watersheds across the country have differing levels and types of water quality concerns due to both underlying environmental factors such as topography, weather, and soil characteristics, and differences in human populations and industrial and agricultural activities.

Agriculture impacts water quality through soil disturbance and application of nutrients and chemical products to the land, some of which can be lost through surface and subsurface flow during rainfall events or irrigation applications. Agricultural water quality concerns focus on the fate of products applied, and this fate is determined in large part by rainfall patterns, soil type, slope, terrain, landscape configuration, and local geology that influences subsurface water flow.

Another important factor is that in-stream water quality, in particular concentrations of nutrients, is influenced by both current practices and the legacy effects of historical practices. Legacy effects occur in two ways. One is through groundwater storage, which can become high in nutrient concentrations through subsurface leaching and then enter the surface hydrologic system years or decades later. In addition, there is evidence of lag times influenced by climate variability; one study of the Upper Midwest found anomalously high nitrate concentrations in streams in 2013, a year of normal flow that followed the drought year of 2012 [92]. They hypothesized that the nitrogen accumulated in the soil in the drought year and was mobilized by precipitation the following year.

The combination of these various factors emphasizes that monitoring for trends in water quality is a long-term effort. Changes across a region in practices, for example, may not have an immediate impact, but should be apparent over the longer term of decades.

The USGS network of measurements has been extensively used in research, and there are several relevant studies that assess trends over time. The measurements also formed the foundation for an assessment of trends over the 1993–2003 time period in a comprehensive report [93], which found that nutrient concentrations in streams and groundwater in basins that have significant agricultural or urban land uses are higher than background levels, and noted the need to continue monitoring and developing mitigation strategies for waters with high nutrient levels in order to minimize negative human health or environmental outcomes.

These measured data can be correlated with different land uses, such as agriculture, but water quality at any point in a stream is influenced by a wide range of natural and anthropogenic point and non-point sources of nutrients and contaminants from the entire watershed, making it difficult to discern the primary drivers for changes seen at monitoring stations. For some locations, the monitoring stations have been in place for decades, enabling long-term analysis of trends that can be used to assess effectiveness of efforts to mitigate nutrient losses. For example, monitoring stations in Washington state detected an improvement in water quality of reduced total phosphorous following the implementation of best management practices to reduce erosion [93].

On balance, the trend analysis from 1993 to 2003 was able to discern increasing nutrient trends as a result of all human activities to above-recommended levels in 21 percent of streams that had previously been below such levels, while detecting improvements in only 1 percent of streams that had previously been above recommended levels [93]. The findings emphasize the local nature of water quality challenges and the complexity of developing and adopting appropriate solutions.

For example, an assessment of in-stream nitrate levels and flows for the Mississippi and its tributaries found several clear trends over the period 1980–2010 [94]. While overall nitrate remained relatively steady or increased through the first 20 years, trends from 2000 to 2010 indicated declines in nitrate concentration of 11–15 percent in the Iowa and Illinois Rivers. However, during that same period, increases of 17–70 percent were seen in the Missouri and Upper Mississippi Rivers, with the combined effect of these trends being an observed increase in nitrate at monitoring stations on the Lower Mississippi River. Another important trend noted was that the nitrate concentration during low river flow was observed to increase over the study period; this indicates that there is a substantial contribution to streamflow nitrate from either groundwater sources, non-agricultural point sources, or both. If some portion is coming from groundwater, this nitrate may be a result of "legacy" effects, resulting from historically high rates of nitrogen leaching. Groundwater nitrate, and its legacy effects, will be slower to respond to changes in conservation practices that reduce present-day nitrate loss from farm fields.

Water Quality and Agricultural Practices

While these measurements capture all sources of potential nutrient and contaminant contributions to streams, they can only be correlated to agriculture (or any other cause) at a macro scale. For example, using monitoring stations with very long-term records, from the 1920s to present, Stets et al. [95] found a clear correlation between increasing river nitrate levels and the extent of agricultural land use in a basin. However, identifying the role of agriculture in a given year or even over a decade is more challenging.

In order to understand the potential trends from changes in agricultural practices, therefore, USDA has been conducting major watershed modeling assessments of water quality in the context of agricultural conservation practices. These studies, under the Conservation Effects Assessment Project (CEAP), included both measured and modeled assessments of agricultural water quality for a single time period (2003–2006) [96]. Several scenarios, including actual farm management practices during that time period, and a baseline scenario assuming no conservation practice adoption were evaluated. While CEAP studies do not provide a time series, the use of simulation models and scenarios does allow consideration of how effective conservation practices are in different locations and their impact on water quality outcomes. For this report, we will focus on considering the findings of the major watershed cropland reports that, taken together, provide insight into current water quality challenges and opportunities associated with U.S. agriculture.

CEAP is an extensive program with several major research directions; here, we will focus on the aggregate or summary information at the large watershed scale in order to inform discussion of national trends. In addition, a number of in-depth watershed studies were conducted [97, 98, 99]. These studies provide findings specific to the watersheds studied and are important resources for region-specific understanding of the availability and effectiveness of specific conservation practices. While these studies are not included in the national-level summary provided here, they are a valuable resource for understanding the complexity of water quality concerns and potential solutions. Those reports and other materials are available from the CEAP web portal [96].

Watershed Assessment Summaries

In order to conduct the watershed assessments, scientists collected information from the Natural Resources Inventory (NRI) and the National Agricultural Statistics Service (NASS). They also conducted a separate set of farmer surveys at NRI-identified statistical sampling points and gathered field-specific information on conservation practices. Through a statistical sampling framework, 20,000 NRI sample points were selected that represent 98 percent of cultivated cropland. With these data, two simulation models, SWAT/HUMUS [100, 101] and APEX [102], were applied at the field scale and integrated into a large watershed modeling framework for basin analysis. Duriancik et al. [97] provide an overview of the program methodology and uncertainty considerations.

These sample points were then simulated for both actual practices as reported in the farmer survey, and an alternative scenario of "no conservation practices" designed to represent these same lands but without conservation practice adoption. By comparing the two scenarios, the reports draw conclusions about the effect that conservation practice adoption has had on water quality outcomes. The assessments consider both the field-level difference and the watershed outlet difference in water quality outcomes. It is important to emphasize that these are results of a scenario-based modeling study and do not reflect actual water quality measurements or trends over time. Thus the findings do not necessarily correlate to real-world changes in water quality outcomes. They do, however, provide insight into the best available scientific understanding of the water quality impacts of conservation practice adoption.

USGS Hydrologic Unit Code (HUC)	Basin	Abbreviation	Citation
02 (0205,0206,0207,0208)	Chesapeake Bay Region	CBR	USDA, 2011 [103]
02 (0204)	Delaware River Basin	DRB	USDA, 2014 [104]
03	South Atlantic-Gulf Basin	SAGB	USDA, 2014 [105]
04	Great Lakes Region	GLR	USDA, 2011 [106]
05 and 06	Ohio Tennessee River Basin	OTRB	USDA, 2011[107]
07	Upper Mississippi River Basin	UMRB	USDA, 2012 [108]
08	Lower Mississippi River Basin	LMRB	USDA, 2013 [109]
09	Souris-Red-Rainy Basin	SRRB	USDA, 2014 [110]
10	Missouri River Basin	MRB	USDA, 2012 [111]
11	Arkansas-White-Red Basin	AWRB	USDA, 2013 [112]
12	Texas Gulf Basin	TGB	USDA, 2015 [113]
17	Pacific Northwest Basin	PNB	USDA, 2014 [114]

Table 2.2: Major watersheds considered in the CEAP Cropland Assessment Reports.

We considered all watershed assessment reports published prior to June 2016. Each basin listed in Table 2.2 has somewhat different water quality concerns and history of conservation practice adoption. All basins were assessed for the difference conservation practice adoption has made on surface and subsurface nitrogen loss, phosphorous loss, sediment loss, and reduction in pesticide risk.

Edge-of-Field Water Quality Outcomes

Figure 2.14 illustrates the percentage reduction in sediment loss from edge-of-field for each river basin. The improvements are largest in the Missouri, Arkansas-White-Red, and Upper Mississippi Basins as a result of conservation practices including riparian buffer treatments, Conservation Reserve Program (CRP) set-asides, reductions in tillage, improved nutrient management, and increases in residue cover. The period of assessment for CEAP predates widespread adoption of cover crops, which would be expected to further reduce losses of sediment from cropland, particularly in the winter months [11].

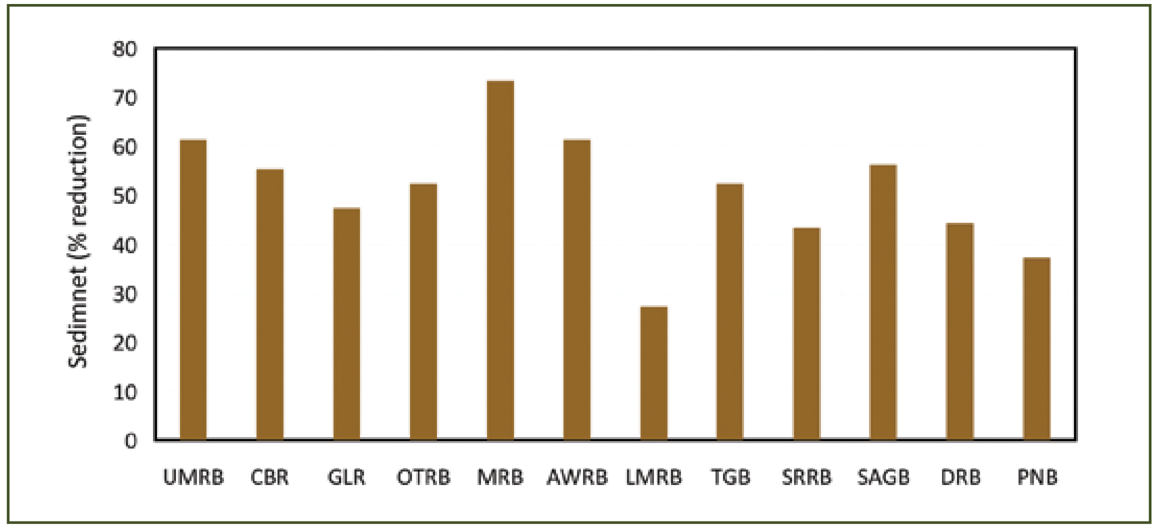


Figure 2.14: Simulated reductions in edge-of-field losses of sediment (percentage change) through conservation practice adoption (2003-06)

Improvements in nutrient loss due to conservation practice adoption were also simulated for all basins studied, particularly in the Souris-Red-Rainy, Missouri, and Arkansas-White-Red, where improvements of at least 50 percent in one nutrient category were simulated (Figure 2.15). In many basins, in particular those with extensive tile drainage (UMRB, OTRB), the nitrogen loss in the subsurface has responded less to conservation practice adoption than surface nutrient loss. As subsurface nitrogen percolates through the soil and is routed underneath the field, surface practices such as residue and tillage management and buffer strips have less influence on how much nitrogen is lost.

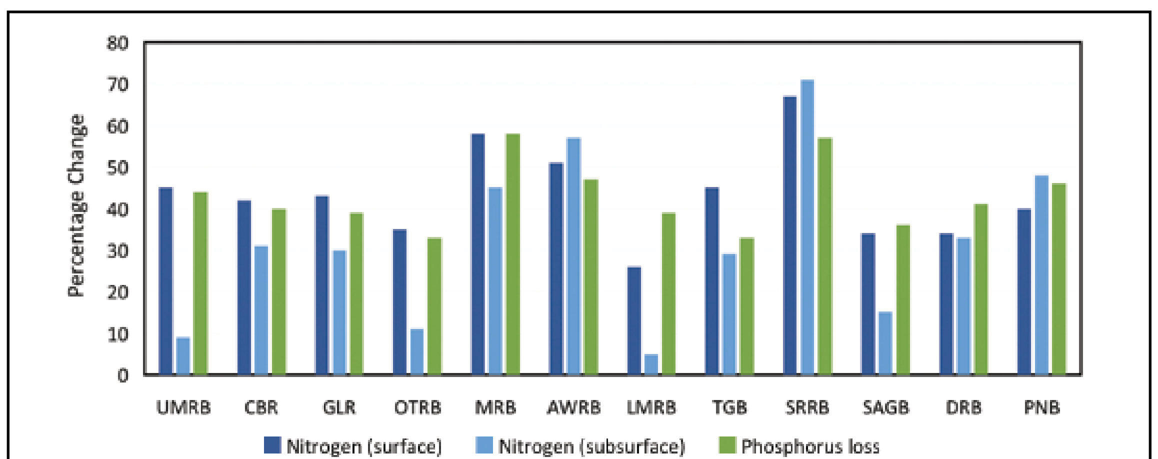


Figure 2.15: Simulated reductions in edge-of-field losses of surface nitrogen and phosphorous and subsurface nitrogen through conservation practice adoption (2003-06).

River and Stream Water Quality Outcomes

In addition to reporting on the cumulative watershed-wide reduction in edge-of-field water quality outcomes, the reports assess the water quality in-stream based on hydrologic routing models (note that the Delaware River Basin report did not include this type of analysis) (Figure 2.16). These findings illustrate significant improvements for in-stream sediment and nutrient loads for the major river basins, with generally the greatest improvement in reduction in sediment loss. In most basins, nitrogen and phosphorous reductions were similar in magnitude.

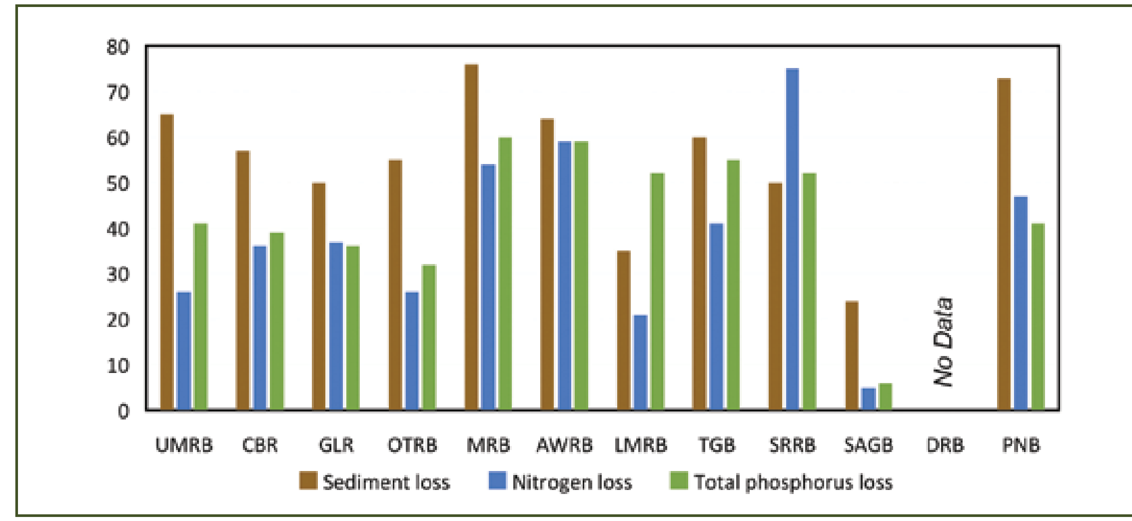


Figure 2.16: Simulated reduction in sediment and nutrient loadings delivered to rivers and streams from cropland sources (2003-06)

Pesticide Risk

The reports also included an assessment of the risks to human health and aquatic ecosystems from pesticide loss, and simulated the reductions in risk associated with the adoption of conservation practices (Figure 2.17). Overall, most basins see the largest improvement in the risk to aquatic ecosystems, with still-significant improvement in the risk to human health.

This first round of the CEAP watershed assessment reports documents simulation studies that indicate considerable improvement in both edge-of-field and in-stream water quality outcomes that can be attributed to conservation practice adoption. While comprehensive and indicative of the impact of conservation practice adoption for the early 2000s, the results provide only a snapshot and cannot be used to determine a trend over time. However, the reports, when taken together, illustrate that conservation practices can be effective at addressing water quality outcomes at a basin level and provide support for efforts to continue identifying appropriate practices and encouraging and supporting more widespread adoption on cropland.

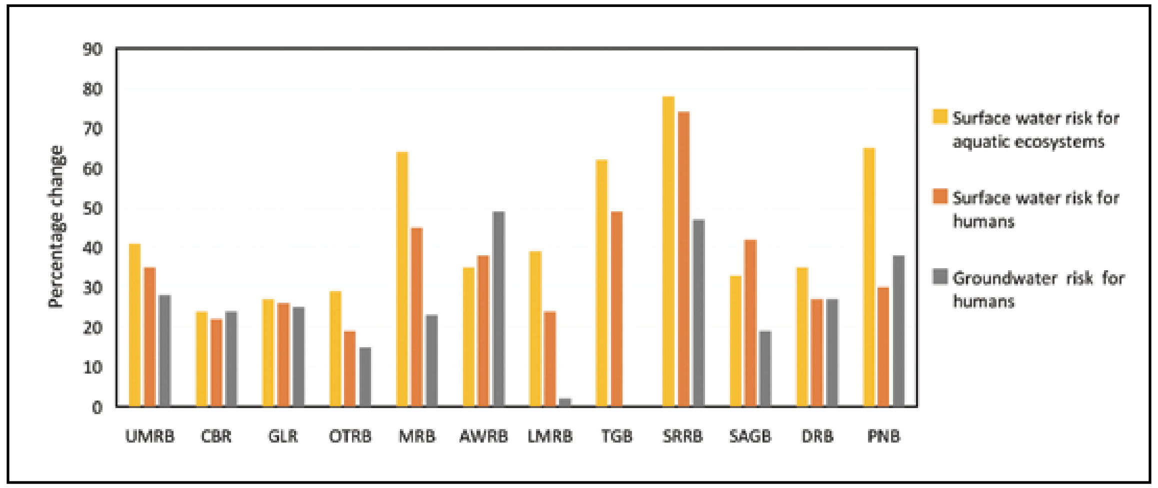


Figure 2.17: Simulated percentage reduction in pesticide risk indicators for humans and aquatic ecosystems due to conservation practice adoption.

PART TWO: NATIONAL TRENDS IN LAND USE AND MANAGEMENT—IMPLICATIONS FOR SUSTAINABILITY

Future National Water Quality Assessments

Both the USGS monitoring station trends and the CEAP conservation practice simulations are currently being updated with an additional decade of information about recent trends in agricultural practices and data on water quality. In the meantime, the data resources gathered and used in reports discussed here continue to support water quality research in the scientific community. It is important to note that while the CEAP studies identify important contributions to water quality improvements from conservation practices, this has generally not yet become apparent in the measurements taken at USGS monitoring stations. This could be due to many factors, including uncertainty in the CEAP modeling, legacy effects of nutrients stored in soils, weather events, and so forth. Thus there remains substantial opportunity for innovation in how to address water quality concerns. Water quality is a unique sustainability concern in how challenging it is to measure at a field or farm level, and in the complexity of factors controlling the environmental outcome at a watershed scale. The scientific community continues to strive to further our understanding of these challenges and assist in developing appropriate solutions.

While a comprehensive assessment of the literature is beyond the scope of this report, a recent publication provides some connection between the USGS water quality modeling sites and the adoption of conservation practices on cropland. Garcia et al. [115] recently applied a USGS water quality model (SPARROW) to see whether observed water quality changes could be correlated with the adoption of conservation practices on farmland. Focusing on the Upper Mississippi River, they found that higher rates of conservation practice adoption were associated with reductions in both total nitrogen and total phosphorous loads. These changes corresponded to reductions of 5–34 percent for nitrogen and 1–10 percent for phosphorous.

While just one snapshot, the results of this study provide empirical evidence at the regional scale that conservation practices had a statistically detectable effect on nitrogen, and to a lesser extent on phosphorus, loadings in streams and rivers of the Upper Mississippi Basin. Combined with some encouraging trends observed by the USGS monitoring stations in the Iowa and Illinois Rivers, and the CEAP study indications of conservation practice effectiveness, these lines of evidence provide encouragement for continued adoption of conservation practices by illustrating that they can make a difference, and that proactive efforts by farmers are resulting in a positive impact in overall water quality at a regional level.

PART THREE:
Socioeconomic Indicators

Field to Market has defined sustainable agriculture as meeting the needs of the present while improving the ability of future generations to meet their own needs by focusing on these specific, critical outcomes:

- Increasing agricultural productivity to meet future nutritional needs
- Improving the environment, including water, soil, and habitat
- Improving human health through access to safe, nutritious food
- Improving the social and economic well-being of agricultural communities

Social and economic sustainability are critical to every farm operation and can both be enhanced by enabling producers to work toward continuous improvement in environmental outcomes. In Part One, we presented evidence of how crop yield increases can influence production efficiency for a range of environmental sustainability indicators; here we consider a set of indicators that are directly tied to the social and economic well-being of the farmer and farming communities. These indicators were first developed and presented in the 2012 Field to Market report [13] and here are updated with the most recent data from USDA as well as other government agencies that conduct surveys on economics, labor, and safety. The indicators represent the same information as in the 2012 report, but they have been renamed (see Table 3.1). The five indicators are Farm Financial Health, Farm Profitability, Generation of Economic Value, Worker Safety, and Labor Productivity.

These indicators are national-scale measures that use publicly available data to evaluate trends over time. The time period of analysis varies by indicator and, where possible, encompasses as much of the range between 1980 and 2015 as possible. However, much of the source data are only available for more recent years, and changes in data collection and analysis over the years have made it challenging to develop a full 36-year dataset for all indicators. The first year of analysis is indicated in Table 3.1, and all indicators are calculated through 2015.

The indicators were developed to focus on the outcomes of production on farm, and to represent social and economic factors over which farmers have some measure of influence through their choices of management practices. Similar to the environmental indicators, the scope of the economic indicators is intended to reflect factors and activities relevant to the production of a crop in a given year, rather than a full economic assessment of all activities undertaken by a producer that might include machine hire, custom work, or other activities. Crop-specific data are available for only two of the indicators—Farm Profitability and Labor Productivity—and for only eight of the 10 crops detailed in the environmental indicators (Table 3.2). The remaining three indicators represent more aggregate combinations of crops, determined by how the source data were collected and reported.

Type	Indicator Name	Measure	Crop Specific	First Year
Economic	Farm Financial Health	Debt to Asset Ratio		1996
	Farm Profitability	Return Above Variable Costs	X	1980
	Generation of Economic Value	Tax Base Contribution (GDP)		1997
Social	Worker Safety	Injuries		1994
		Fatalities		1993
	Labor Productivity	Labor Hours	X	1990

Table 3.1. Socioeconomic indicators and the first year of data available for analysis.

METHODOLOGY

The primary data for the indicators reported here are annual data from the USDA Farm Cost and Returns data [116] and the Agricultural Resource Management Survey (ARMS) dataset [117]. ARMS data provide information about the quantity of inputs being used and the mix of technologies employed in the production of a given crop. Major field and row crops are surveyed approximately every five years. The most recent ARMS surveys for the crops we cover are barley (2011), corn (2010), cotton (2015), peanuts (2013), rice (2013), soybeans (2012), sugar beets (2007), and wheat (2009) [3]. Note that ARMS has stopped collecting survey information for sugar beets; thus, we use historical information up to 2007 and then project forward, holding crop management constant and using the most recent data on yield and other factors. For all indicators, we calculate the trends using a three- or five-year moving average, determined by the length of record of the source information. This assists in smoothing annual variations, providing a clearer picture of the long-term trend.

For the two indicators where crop-specific information is available—Farm Profitability and Labor Productivity—we use the same yield definitions for the crops as in Part One of this report (Table 3.2).

Crop	Yield Unit	Description
BARLEY	bu.	Bushel, 48 lb. of barley grain per bushel
CORN	bu.	Bushel, 56 lb. of corn grain per bushel
COTTON	lb. of lint	Pounds of lint
PEANUTS	lb.	Pounds (lbs.)
RICE	cwt.	Hundred weight (100 lb.)
SOYBEANS	bu.	Bushel, 60 lb. of soybean seed per bushel
SUGAR BEETS	ton	2,000 lb.
WHEAT	bu.	Bushel, 60 lb. of wheat grain per bushel

Table 3.2. Crops and yield definitions used in the calculation of the Farm Profitability and Labor Productivity indicators.

The co-product distinctions for cotton and wheat are also the same as in Part One; we consider here primary outputs only: cotton for lint (83 percent) and wheat for grain (96.6 percent). Thus, where necessary, the indicator data are corrected to remove the portion attributed to cottonseed (17 percent) or wheat straw (3.4 percent). Two of the crops from Part One—corn for silage and potatoes—do not have sufficient representation in the necessary data sources to produce these indicators.

Together, the production of these eight crops represents 243 million acres of agricultural cropland use in the U.S. in 2015, when the combined value of the crops was over $100 billion [4].

Farm Financial Health Indicator

The Farm Financial Health Indicator reflects the debt-to-asset ratio, defined as the portion of the farm's assets that is being financed through debt. A debt-to-asset ratio of 0.4 or greater indicates higher debt when compared to assets (farms that are highly leveraged) and therefore may be at greater risk of foreclosure if unable to meet debt repayment obligations.

Data for this indicator are from the USDA ERS Farm Business and Household Survey Data's information for all farms from 1996 to 2015 [119, 120]. These data are collected for a farm operation and categorized for reporting based on the percentage of income derived from production of different crop or livestock categories. For this indicator, we include farms that report 50 percent or more of income from cash grains, which include barley, corn, rice, sorghum, soybeans, wheat, oats, and general cash grains where no single grain accounts for the majority of production [121]. This category is not an exact match to crops in the Field to Market program, but it provides a useful approximation for our purpose of assessing trends over time.

Farm Profitability Indicator

The Farm Profitability indicator calculates the financial returns above variable costs, providing a measure of how the profitability of farms has changed over time. This indicator helps growers evaluate alternative strategies for improving their economic sustainability through the most efficient use of their land, capital, and labor. The indicator calculations include variable costs, defined as the out-of-pocket cash expenses paid for inputs unique to the commodity being produced. These expenses depend on production practices and on the amount and price of inputs required such as seed, fertilizer, feed, chemicals, and hired labor. The indicator does not include land costs (rent or taxes) or fixed costs such as equipment where the accounting methodology includes depreciation.

The data for this indicator are from USDA Farm Cost and Returns datasets [116] and the ARMS dataset [117]. The ARMS data provide information about the quantity of inputs being used and the mix of technology employed in the production of a given crop, and are based on surveys conducted approximately every five years. Data on the prices farmers pay for inputs are collected annually and published in the USDA National Agricultural Statistics Service (NASS) Agricultural Prices report series [121]. Thus, this indicator is calculated for the eight crops listed in Table 3.2 but is not available for corn for silage or potatoes.

The Farm Profitability indicator is calculated on a planted-acre basis; if any abandonment occurs, it is amortized across the crop that was produced. First, gross income (returns) is calculated as the sum of production from primary and secondary products (for example, wheat grain and straw) plus any government payments provided that are dependent on the act of producing the crop. Loan deficiency payments are included because they influence profitability of a crop and thus are a factor in farmer decisions on what crops to plant in a given year. Also included are crop insurance payments, calculated as the net cost (premiums minus subsidies) and the total payout per acre. Other government payments that are made irrespective of whether or not a crop is planted (fixed payments) are not included. Second, aggregate cost is calculated by combining costs for fertilizer, seed, fuel, chemicals, repairs, paid labor, and other variable costs. Fixed costs such as land and land rental, equipment depreciation, and payments to management are not included.

Then, the variable costs are subtracted from the returns. The result is deflated by the Consumer Price Index (CPI), providing an inflation-adjusted basis measure that represents inflation-corrected income, or a measure of farm profitability. This indicator is representative of income that can be used to pay ownership costs for land, machinery, and improvements as well as for living expenses and, when considered as a trend over time, is intended to reflect whether the returns from growing a certain crop are keeping up with inflation.

The Farm Profitability indicator is normalized to year 2000 real dollars to adjust for inflation. It is presented as a five-year moving average so that the volatility from single-year fluctuations is muted and the value represents the average over a longer period of years. The measure is presented in two ways, on a per-planted-acre basis and also on a per-unit-of-output (bushel, pound, cwt.) basis.

Generation of Economic Value Indicator

The Generation of Economic Value indicator reflects the direct contribution of agricultural production at the farm gate to state and national gross domestic product (GDP). Consistent with the environmental indicators, the specific data selected represent the economic value of the products at the first point of sale, and are not intended to capture the GDP contribution of the entire agriculture sector. Data for this indicator are taken from the U.S. Bureau of Economic Analysis [122], which combines crops and livestock into one category; thus, this indicator reflects a broader range of products than the other indicators presented here. GDP is the value of all goods and services produced, less the value of goods and services used in production. National GDP also includes a range of government and military labor and equipment.

Worker Safety Indicator

The Worker Safety indicator is represented by two measures from the U.S. Bureau of Labor Statistics (BLS): worker illness and injury, and fatalities. These data use a classification system that groups agriculture into several categories based on the product produced [123]. For these indicators, we created a single category defined as all crop farms less those that grow specialty crops, including vegetables, fruits and nuts, greenhouse crops, or horticultural specialties for commercial purposes. The expectation is that the farms that fall into this classification are largely crop farms growing field and row crops. The data are presented in absolute terms rather than incidence per measure of output. Human lives and significant injuries are not something that should be considered as a tradeoff to productivity or output, and the aim of any employer should be zero.

Data for non-fatal injuries must be reported to BLS only by businesses with more than 10 employees. This reporting threshold excludes roughly 90 percent of all farms, but it does capture 57 percent of all farm labor. However, geographic distribution of this coverage is not uniform. For example, the portion of farms in California with more than 10 employees is 25 percent, and the share of their labor covered is 85 percent. In contrast, in Iowa, the share of farms represented is 1 percent, while the share of farm labor is 26 percent.

Despite the lack of representation of small farms in the non-fatal injury data, the measure can be used as an indicator of trends in the farm workplace. The data were analyzed both in terms of incidence of one or more lost workdays and as an estimate of the cumulative number of lost workdays for the year. While the data include statistics on the type of injury and cause of death, these were thinly populated for agriculture and thus were not included here.

The second measure of the Worker Safety indicator is fatalities. Data for fatalities by industry classification are available from 1993 through 2014 from the BLS Census of Fatal Occupational Injuries [124]. Data on workplace fatalities are reported by industry for companies of all sizes, including single-employee and owner-operator workplaces. Thus, the data for the crop farms are a more complete representation of trends.

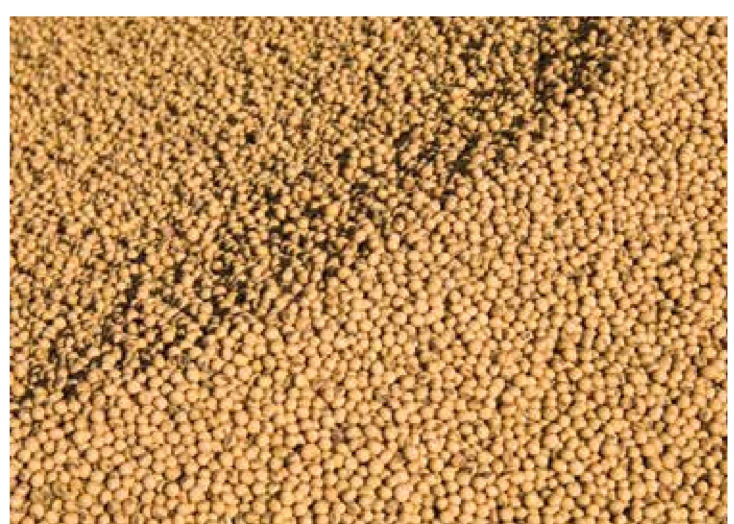
Labor Productivity Indicator

The Labor Productivity indicator is calculated using labor hours derived from the USDA Economic Research Service (ERS) Commodities Cost and Returns data [116]. This indicator is a measure of the efficiency of labor on both a per-acre basis (e.g., hours necessary to cultivate the field) and on a per-unit-output basis. While a per-acre basis is more commonly used for farm planning and reporting, we include the per-unit-output measure to ensure consistency with the environmental indicators as we look at trends in efficiency over time. These data are available on a crop-specific basis and thus are included for the eight crops listed in Table 3.2.

To generate the indicator, the data by crop on the cost of hired labor and the opportunity cost of unpaid labor are combined to produce a total cost per acre. Then, the farm labor wage rate from NASS surveys [125] is used to convert this to labor hours per acre:

- (Hired labor cost per planted acre + Unpaid labor cost per planted acre)/(Wage rate)

These economic data are not available on an annual basis; as with the environmental indicators, a linear interpolation is used to calculate an annual time series. The labor hours per acre are then multiplied by the national planted acreage, and divided by production to produce the indicator in the form of labor hours per unit of production. A three-year centered moving average was used to smooth the influence of single data points.



RESULTS

Given the variation between the five indicators in both the time period of analysis that was possible and the scope of crop or agricultural land that is included in the available data, making generalizations across the indicators is challenging. A summary table of four of the indicators (Table 3.3) illustrates the average change and direction of change over the available time period. These percentage changes are derived from the linear interpolation equations fitted to each trend series; thus, they reflect the percentage change of that overall trend between the first and last years of analysis.

- **Farm Financial Health Indicator** (1996–2015)
  - The debt-to-asset ratio decreased (improved) (-23 percent) for general cash grain farms.
- **Generation of Economic Value Indicator** (1997–2015)
  - The contribution of agriculture to the national GDP has increased (30 percent).
- **Worker Safety Indicator** (1995–2015)
  - The number of work-related injuries decreased (-40 percent) for all crop-producing farms with 11 or more employees.
  - The number of lost workdays (-86 percent) and the incidence of one or more workdays lost (-54 percent) both decreased for crop farms.
  - Fatalities decreased (-45 percent) for crop farms (excluding fruit, vegetable, and horticulture farms).
- **Labor Productivity Indicator** (1990–2015)
  - The implied time to produce corn (-67 percent, -82 percent), cotton (-78 percent, -83 percent), peanuts (-54 percent, -73 percent), rice (-47 percent, -63 percent), soybeans (-66 percent, -77 percent), sugar beets (-41 percent, -58 percent), and wheat (-18 percent, -34 percent) all declined (improved) on both a per-acre and per-unit-output basis, indicating an improvement in efficiency of production. While Labor Productivity, measured as hours per acre increased for barley (+13), it declined (improved) slightly on a per bushel basis (-19 percent).

In summary, the indicators for Farm Financial Health and Worker Safety improved over their respective time periods, while the Labor Productivity indicator declined, indicating improved efficiency of production. The Farm Profitability indicator illustrates that the agricultural sector's contribution to national GDP has increased over the explored time period.

Indicator	Crops Included	Measurement	Time Period	Percent Change* 1980–2015	
				Trend Direction	Entire Period
Farm Financial Health	Cash Grain Farms	Debt-to-Asset Ratio	1996–2015	↓	(23)
Generation of Economic Value	All Crops and Livestock	GDP Contribution	1997–2015	↑	193
		Share of Total	1997–2015	↑	30
Worker Safety	Crop Farms, Excluding Fruit, Vegetable, and Horticulture Farms	Non-Fatal Injuries—Number	1994–2014	↓	(40)
		Workdays Lost	1995–2014	↓	(86)
		One or More Days Lost	1995–2014	↓	(54)
		Number of Fatalities	1993–2014	↓	(45)
Labor Hours	Barley	Hours/Planted Acre	1990–2015	↑	13
		Hours/Bushel	1990–2015	↓	(19)
	Corn	Hours/Planted Acre	1990–2015	↓	(67)
		Hours/Bushel	1990–2015	↓	(82)
	Cotton	Hours/Planted Acre	1990–2015	↓	(78)
		Hours/Lb. Lint	1990–2015	↓	(82)
	Peanuts	Hours/Planted Acre	1990–2015	↓	(54)
		Hours/Pounds	1990–2015	↓	(73)
	Rice	Hours/Planted Acre	1990–2015	↓	(47)
		Hours/Cwt.	1990–2015	↓	(63)
	Soybeans	Hours/Planted Acre	1993–2015	↓	(66)
		Hours/Bushel	1993–2015	↓	(77)
	Sugar Beets	Hours/Planted Acre	1990–2015	↓	(41)
		Hours/Short Ton	1990–2015	↓	(58)
	Wheat	Hours/Planted Acre	1993–2015	↓	(18)
		Hours/Bushel	1993–2015	↓	(34)

Table 3.3. Socioeconomic Indicators Summary of Results

Results for the Farm Profitability indicator (measured as returns over variable costs) are illustrated in Table 3.4. The linear trends are not included here, as in this crop-specific indicator there has been significant variation across the time period. For all crops, the 2015 value was lower than the maximum value over the time period, on both per-acre and per-unit-output measures. Trends in early years vary by crop, but most illustrate an increasing trend from the early 2000s through 2013, followed by a plateauing or slight reduction in 2014 and 2015.

Indicator	Crop	Measurement	Real Dollar Value (1980–2015)			
			2015 Level	Mean	Min.	Max.
Farm Profitability	Barley	$/Acre	130	79	50	133
		$/Bushel	2.2	1.5	0.9	2.3
	Corn	$/Acre	272	170	106	314
		$/Bushel	2.8	1.4	0.8	3.1
	Cotton	$/Acre	111	138	64	194
		$/Lb. Lint	0.2	0.2	0.1	0.4
	Peanuts	$/Acre	339	343	184	504
		$/Pound	0.1	0.1	0.1	0.2
	Rice	$/Acre	380	228	127	412
		$/Cwt.	5.2	3.7	2.3	6.7
	Sugar Beets	$/Acre	572	515	347	727
		$/Short Ton	21.2	23.7	16.9	34.6
	Soybeans	$/Acre	258	185	129	278
		$/Bushel	6.0	5.2	3.4	8.0
	Wheat	$/Acre	107	74	48	116
		$/Bushel	2.8	2.2	1.4	3.5

Table 3.4. Summary of Results—Farm Profitability Indicator

Results for each indicator are presented and described below in greater depth. We have purposefully avoided speculation regarding the practices and drivers that may have influenced the outcomes in this analysis. Management decisions by U.S. agricultural producers are guided by many factors, including international price signals, Farm Bill policies, incentive programs such as the Conservation Reserve Program, and biofuel policies and incentives. Where the data that were utilized to construct the metric can explain changes over time, some interpretation is given. However, thorough attribution of trends to specific causes is beyond the scope of this report.

Farm Financial Health Indicator

The Farm Financial Health indicator shows the continued strong financial position (measured by the debt-to-asset ratio) for U.S. farms that specialize in the production of cash grains (Figure 3.1). By 2015, the most current year that data are available, the ratio was at 12.2, compared with 14.8 in 1996. The lowest value over the time period was 11.3, in 2012. The strong performance of this measure is driven by two main factors: strength in land values and reluctance by farmers to increase debt. The financial measure did see an upward spike in 2002 due to a drop in property asset values and crop inventories while experiencing an upward movement in borrowing. Grain producers experienced record income levels around 2010 that caused land values to increase and producers to pay cash for purchases that might otherwise have been financed. In the past two years, falling commodity prices have had a negative effect on cash grain farm incomes that is reflected in the indicator.

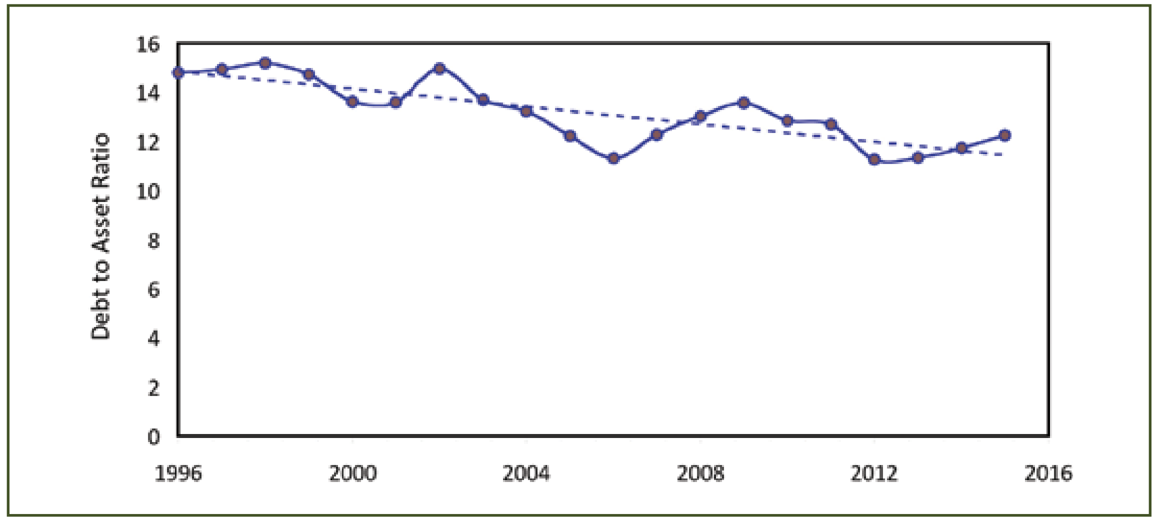


Figure 3.1. The Farm Financial Health Indicator—debt-to-asset ratio for general cash grain farms.

Farm Profitability Indicator

Several factors can impact the Farm Profitability indicator for crop producers. This indicator is defined as the financial returns above the variable costs of operation, and over time, increases in expenditures for purchased inputs can reduce the net financial return if output prices do not increase at the same rate. By contrast, increases in yield or productivity can increase the returns on a per-acre basis and potentially reduce the costs on a per-unit basis; for example, if yields increase but the same amount of fuel is used in operations for establishment and care. In a given growing season, the most significant factor impacting net returns will be crop price changes and yield variation due to weather. Variation in crop prices occurs due to a range of external factors and influences that affect all growers of that specific commodity the same. In contrast, variation in crop yield is typically specific to geographic areas due to the influence of weather events, and may or may not have a significant impact on crop prices. The price used in the calculation of crop revenue presented here is based on a harvest price, and includes the impact of quality adjustment and farmers' use of cash-forward contracts. The estimates do not include the impact of farmers' use of futures markets to protect a net price level. The Farm Profitability indicator is presented by crop, and based on a five-year moving average from 1980 to 2015, with the first year shown (1984) representing the average of 1980–1984. Prices have been normalized to year 2000 dollars to eliminate the effects of inflation.

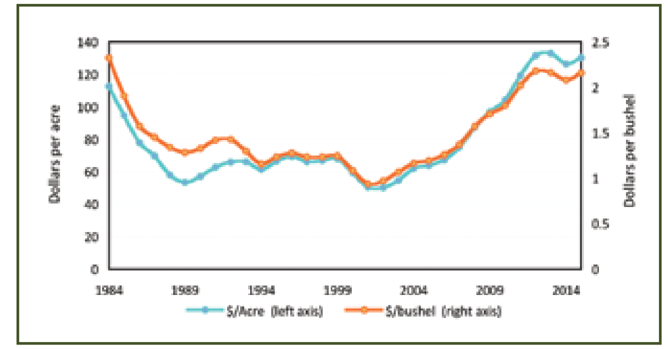


Figure 3.2: Farm Profitability Indicator for barley, real returns above variable costs of production.

BARLEY

The Farm Profitability indicator for barley illustrates a decline through the 1980s followed by stabilization in the 1990s and steady increases from 2002 through 2012. Following this decade of sustained increases in returns both per acre and per bushel, the indicator has remained relatively constant over the past few years (Figure 3.2). This general pattern of declines early in the study period increases in the 2000s, and a more recent stabilization is common among a number of the crops and reflects complex interactions of crop prices and costs of production inputs.

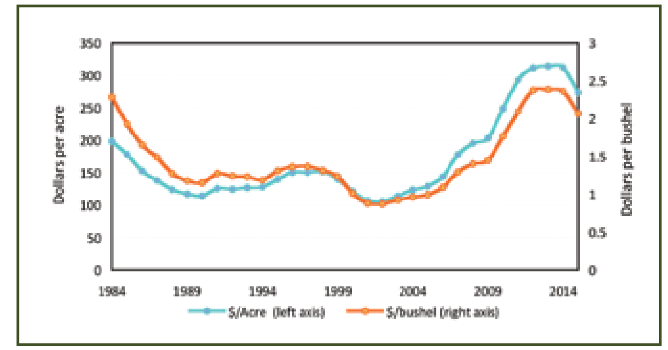


Figure 3.3. Farm Profitability indicator for corn, real returns above variable costs of production

CORN

Measured in year 2000 currency, real net returns from corn production averaged $170 per acre over the period 1980 to 2011, sank to a low in the early 2000s, and rose to a peak of $314 in 2013 (Figure 3.3). On a per bushel basis, corn net returns above variable costs experienced a low in the early 2000s of $0.88 per bushel and a high of $2.38 per bushel in 2013. During the period from 1990 to 2013, corn returns have seen sustained periods of strength. The decline from 2014-2015 is likely due to falling commodity prices.

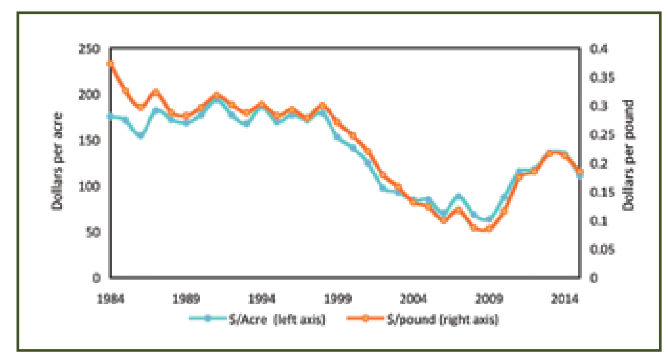


Figure 3.4. Farm Profitability indicator for cotton lint, real returns above variable costs of production.

COTTON LINT

The Farm Profitability indicator for cotton (Figure 3.4) indicates a high value at the beginning of the study period, declining to a low around 2009 but increasing again in recent years. Cotton yields have experienced relatively consistent growth over time with a long-run trend of about 1 percent annually over the past 30 years. These strong yields, and even a near doubling in the season average price, caused real net returns above variable cost to begin to increase or at least stabilize after 2009. The increase in cotton prices lagged behind that of grain crops by a few years, which consequently caused a reduction in cotton acreage. Cotton has seen considerable increases in the cost of production over time, and production challenges in recent years have caused crop insurance payouts to be considerable.

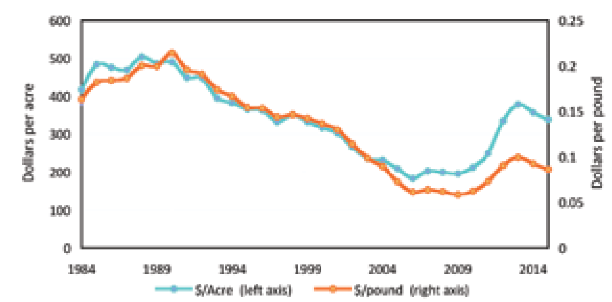


Figure 3.5. Farm Profitability indicator for peanuts, real returns above variable costs of production.

PEANUTS

The Farm Profitability indicator for peanuts shows a trend over time that is similar to cotton lint, with the highest level of profitability occurring in the late 1980s followed by a decline through 2009 and a more recent increase on both a per-acre and per-pound basis (Figure 3.5).

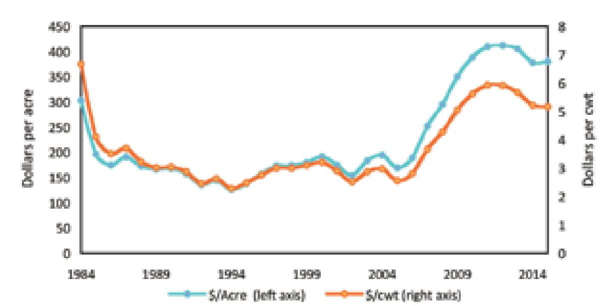


Figure 3.6. Farm Profitability indicator for rice, real returns above variable costs of production.

RICE

The Farm Profitability indicator for rice similarly was high in the early 1980s due to high prices on an inflation-adjusted basis (Figure 3.6). Through the late 1980s and all of the 1990s, rice per acre real returns hovered around $150 to $200 per acre and around $3.00 per hundred weight (cwt.). High crop output prices in recent years and strong yields have allowed per-acre net returns to rise above the past highs and to more than $400 in 2012. Rice returns per cwt. most recently have leveled off slightly below this high. Rice production in the U.S. is fully irrigated; thus, yield variation due to weather is generally less significant than it is for other crops. This may help explain the lower year-to-year variation in returns.

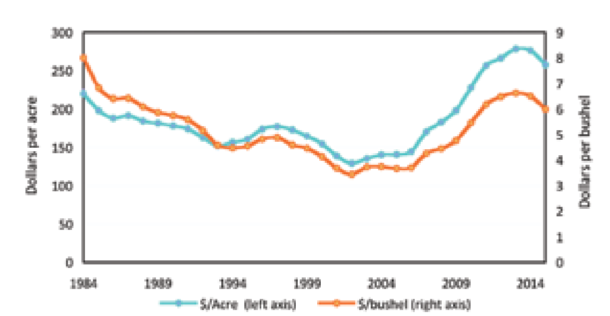


Figure 3.7. Farm Profitability indicator for soybeans, real returns above variable costs of production.

SOYBEANS

Over the period from 1984 through 2015, the Farm Profitability indicator for soybeans experienced the highest values on a per-bushel basis in 1984 and the highest values on a per-acre basis in 2013. Returns over costs in 2015 are down from the peak due to the recent decline in crop prices (Figure 3.7).

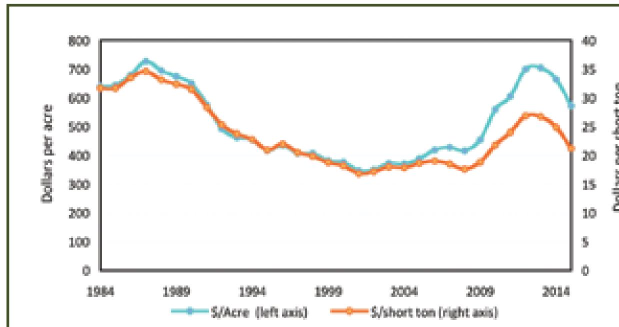


Figure 3.8. Farm Profitability indicator for sugar beets, real returns above variable costs of production.

SUGAR BEETS

The Farm Profitability indicator for sugar beets also experienced a high value of returns over costs per unit output (ton) and per acre early in the study period (Figure 3.8). More recently, the value per acre has increased faster than the value per ton, indicating higher yields that allow greater production per acre but also require additional input costs.

Figure 3.9. Farm Profitability indicator for wheat, real returns above variable costs of production.

WHEAT

Wheat returns peaked in the early 1980s due to high real crop prices and generally favorable yields in the U.S. In 1984 the five-year average per-acre real returns reached a high of $108 and fell to a low of $48 in 2005. The sustained rise in grain price over the past several years has pushed real returns back up to $115 in 2014, with a slight decline in 2015. On a per-bushel basis, high and low wheat returns coincided with the same years as the per-acre measure (Figure 3.8).

Generation of Economic Value Indicator

We include here the contribution of agriculture to the national gross domestic product as an indicator of the potential for agriculture to generate economic value. Data for this indicator allow for only an aggregate sector consideration; therefore, this indicator includes livestock, dairy, and all crops ranging from grains to fruits and vegetables. Thus it is difficult to discern the specific contribution of the commodity crops represented in the Field to Market program. Nevertheless, by including the trends over time we can track the relative value of the sector to the overall U.S. economy. The indicator shows substantial recent increases in both the level and share of GDP in this sector (Figure 3.9), reaching a high of 1.1 percent of national GDP in 2013. As seen in the previous indicator, Farm Profitability, that was also a peak year for prices of many crops. The value of production from the crop and livestock sectors of U.S. agriculture has increased steadily over the period 1997 through 2015. As a share of the national economy, the crop and livestock sectors have also been increasing slightly over the past few years.

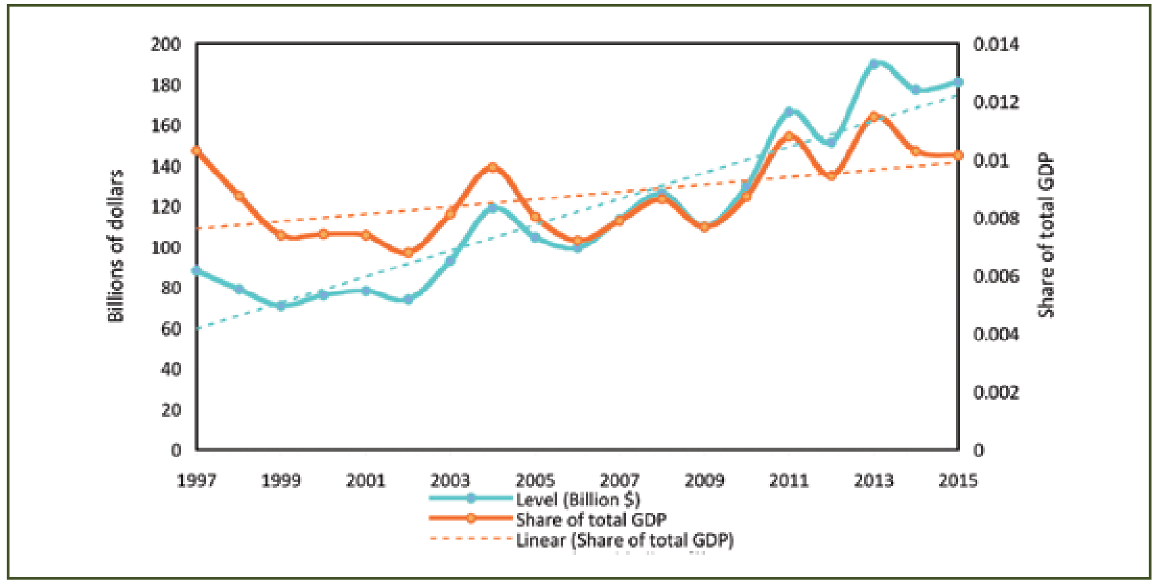


Figure 3.10. Crop and livestock contribution to gross domestic product and share of total GDP – nominal dollars.

Worker Safety Indicator

The two measures included in the Worker Safety indicator are non-fatality injury reports and fatalities as reported to the U.S. Bureau of Labor Statistics.

Both crop farms and all of private industry have seen a considerable reduction in the incidence of injuries, which have declined more than 50 percent since 1994. Labor employed in crop production experienced an injury incidence of 5.6 percent in 2015, somewhat higher than the low of 4.4 percent in 2012 (Figure 3.11). Crop-producing farms experienced considerable reductions from 1994 to 2014 in the number of reported injuries, which declined from 31,000 to 20,000 in 2014, up slightly from the low point in 2009.

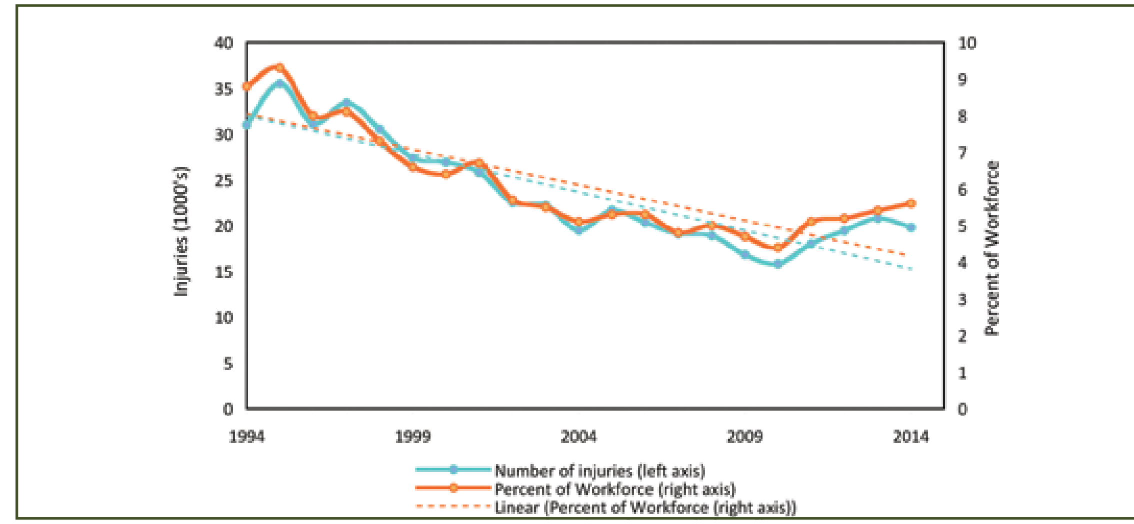


Figure 3.11. Agricultural work-related injuries for all crop-producing farms with more than 10 employees from 1994 through 2014.

Another measure of the impact of injury is how many days of work are lost due to illness or injury and the number of times that one or more workdays were lost. Figure 3.12 illustrates these trends and shows a decline in lost workdays to a low point of 7,330 days in 2014, from a peak of more than five times that many days lost in 1997. The number of occasions where one or more days was lost is more variable, with the lowest point occurring in 2002 and a slight increase since 2010.

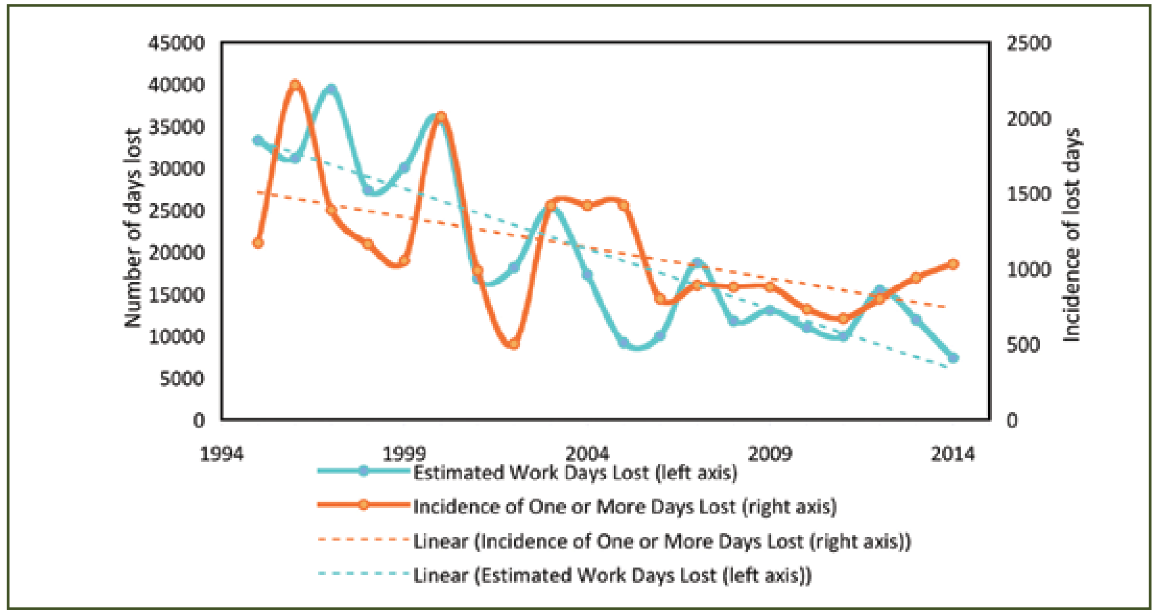


Figure 3.12. Incidence of one or more lost workdays due to injury and estimated days lost, U.S. crop farms – excluding fruit, vegetable, and other specialty crops, 1995–2014.

Finally, we include here the measure of fatalities as an indicator that captures data from all farms. U.S. agriculture remains among the most dangerous industries to work in when measured by incidence of fatal injuries. Data for the period 2006 through 2015 indicates an average fatality incidence of 28.7 occurrences per 100,000 employees, while the private-sector industry average is roughly 4 fatalities for the same period.

The number of fatal injuries on crop-producing farms has declined steadily over time, from 350 in 1994 to 218 in 2014 (Figure 3.13). The largest portion of fatal farm accidents occurs in two areas: vehicle-related incidents and contact with equipment or objects.

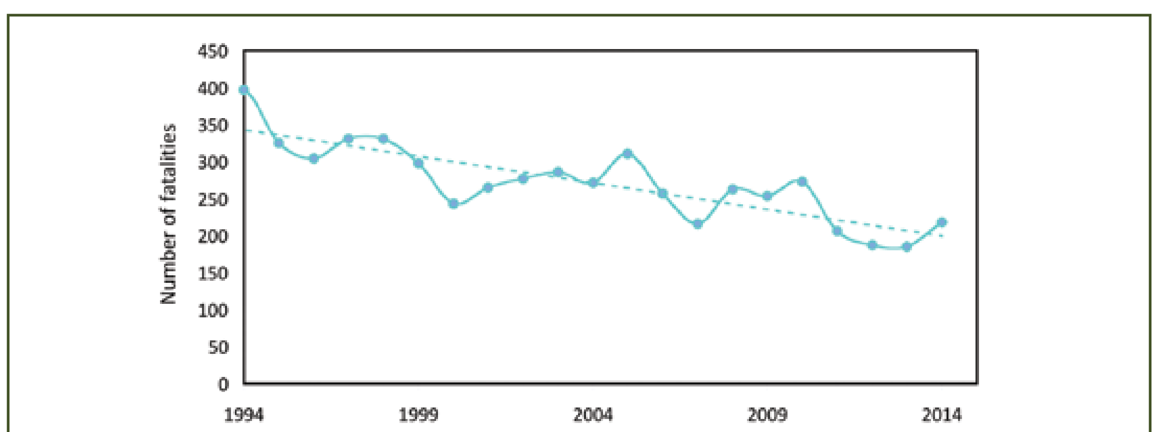


Figure 3.13. Fatalities on crop farms (excluding fruit, vegetable, and horticulture farms), 1993–2014.

Labor Productivity Indicator

The Labor Productivity indicator assesses trends in the number of labor hours required to produce a unit of crop, as well as to cultivate and harvest an acre of that crop. Both are based on USDA data for the period 1990 through 2015; this time period was selected because data are reported in a consistent format that enables a meaningful analysis of trends over time.

Agriculture has a strong trend toward increased efficiency in its use of labor in large part due to technological advances such as GPS navigation, auto-controlled equipment operation, and generally larger equipment overall that reduce the time required for field operations. Most of these technologies have a compounding impact on efficiency over time, and these trends are anticipated to continue as the cost of adoption continues to decline, allowing smaller-scale farms to employ them.

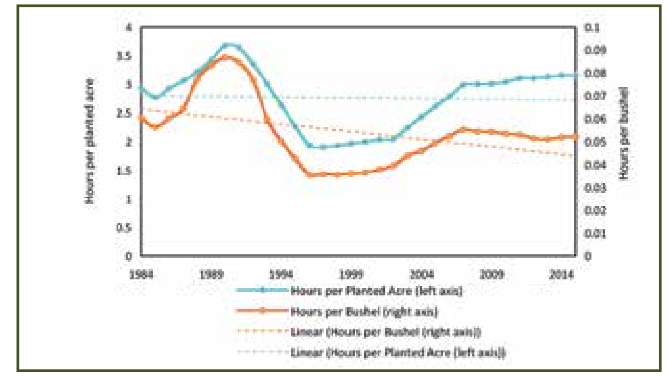


Figure 3.14: Labor Productivity indicator for barley, expressed as the labor hours required to cultivate an acre and to produce a bushel.

BARLEY

The Labor Productivity indicator for barley illustrates that while both labor per acre and per bushel are lower in 2015 than they were in 1990, the decline occurred in the mid-1990s, and the hours required both per acre and per bushel have increased since 2002. Since 2007, labor productivity has largely stabilized for barley.

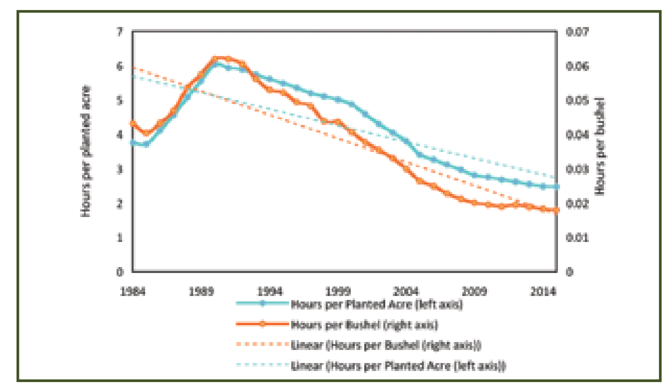


Figure 3.15. Labor Productivity indicator for corn, expressed as the labor hours required to cultivate an acre and to produce a bushel.

CORN

The Labor Productivity indicator for corn improved over the period, as hours to produce an acre and a bushel of corn declined steadily from 1990 to 2010. These improvements have largely leveled off in the past few years, remaining near 0.02 hours per bushel and 2.5 hours per acre (Figure 3.15). These are both significant reductions from the time required in 1990 and are consistent with technology shifts. Strong adoption of reduced tillage and no-till for corn production has reduced the number of trips across a field, while larger tractors and combines have decreased the time necessary to cover an acre. Improved yields have added to these efficiency gains over time.

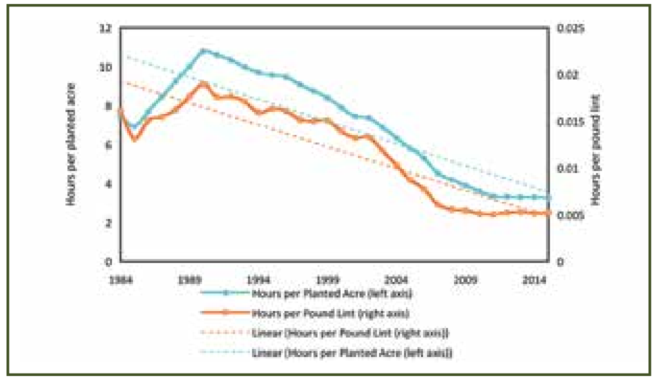


Figure 3.16. Labor Productivity indicator for cotton, expressed as the labor hours required to cultivate an acre and to produce a pound of lint.

COTTON LINT

The Labor Productivity indicator for cotton follows a similar trend, with steady improvements in labor hours per acre and per pound of lint from 1990 to 2010, with a leveling off in recent years. The adoption of insect- and herbicide-tolerant cotton varieties has reduced the time invested in both weed and insect control, while at the same time a steady trend toward less-intensive tillage has cut the hours spent tilling and planting. As with all crops, the size and speed of harvesting equipment have led to reduced time in the field (Figure 3.16).

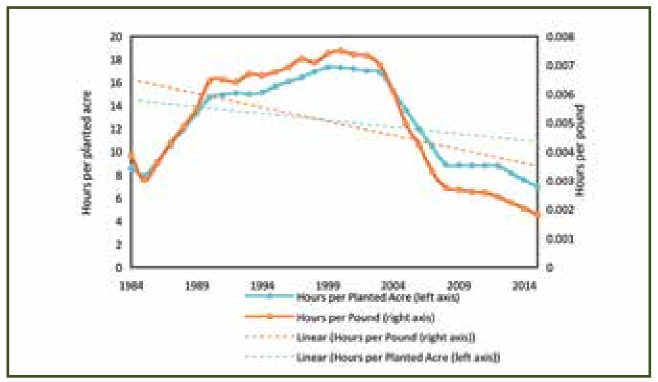


Figure 3.17. Labor Productivity indicator for peanuts, expressed as the labor hours required to cultivate an acre and to produce a pound.

PEANUTS

The Labor Productivity trend for peanuts has declined steadily from the early 2000s to 2015. Labor hours required per acre and per pound increased slightly over the 1990s before declining. Adoption of reduced till technologies occurred later and more slowly for peanuts.

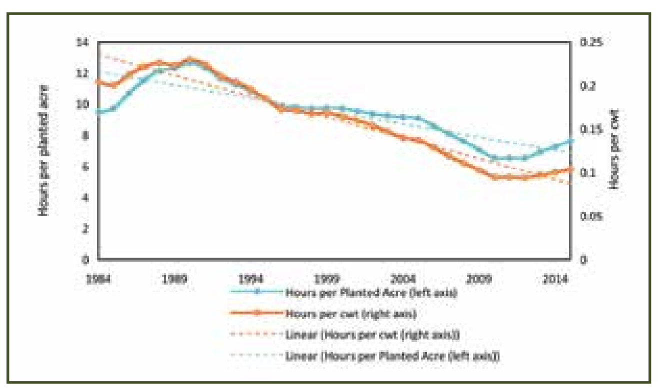


Figure 3.18. Labor Productivity indicator for rice, expressed as the labor hours required to cultivate an acre and to produce a hundredweight (cwt.).

RICE

The Labor Productivity indicator for rice shows that hours required per acre declined from around 13 in 1990 to a low of 6.5 in 2010, before reversing and increasing to 7.6 in 2015 (Figure 3.18). The indicator when expressed per hundredweight (cwt.) of rice produced follows a similar trend. Improved application of irrigation water, along with increased equipment size over time, contributed to improvements in labor efficiency.

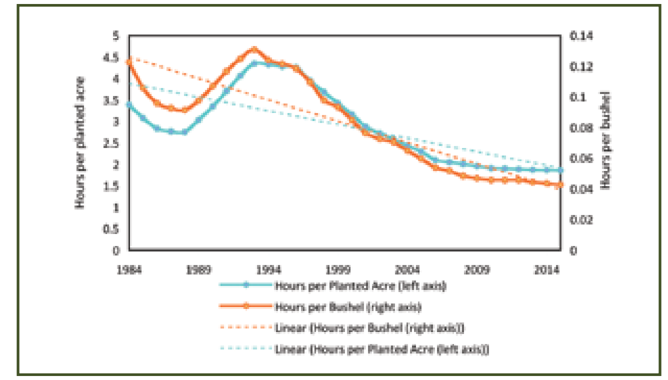


Figure 3.19. Labor Productivity Indicator for soybeans.

SOYBEANS

The Labor Productivity indicator for soybeans shows a decline in labor required from 4.3 hours per acre in 1993 to 1.9 hours in 2011, with the rate then holding steady through 2015 (Figure 3.19). On a per-bushel basis, soybean labor follows a similar trend. The trends are likely driven by technology shifts similar to those noted for corn, with adoption of reduced and no-tillage practices and larger equipment that reduce time necessary for cultivating a crop. Note that due to a discrepancy in the categorization of data from USDA, we do not include the labor hours for 1990–1992 for soybeans.

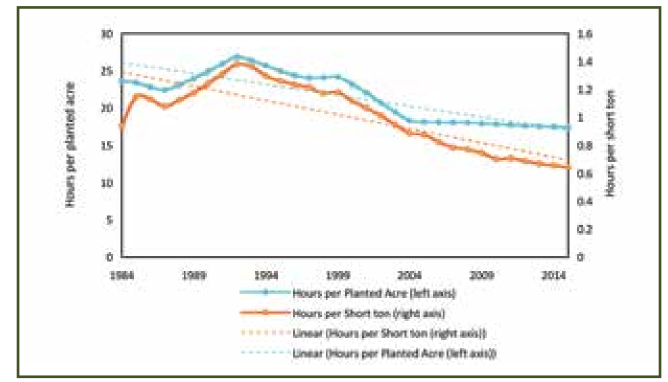


Figure 3.20. Labor Productivity Indicator for sugar beets.

SUGAR BEETS

The Labor Productivity indicator for sugar beets shows a consistent decline from 1992 to 2015 in the labor hours required per unit of production. While the labor required per acre leveled off in the past five to 10 years, labor per short ton continued to decline due to increasing crop yields over this period.

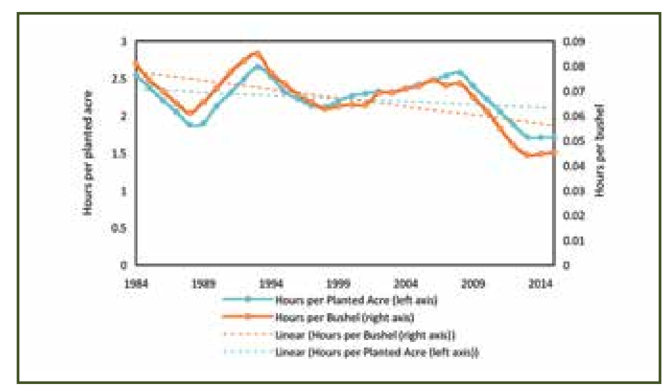


Figure 3.21. Labor Productivity Indicator for wheat.

WHEAT

The Labor Productivity indicator for wheat has overall improved over the 25-year period, with significant declining trends from 1990 to 1998 and again from 2008 to 2013. In the decade from 1998 to 2008, increases in the amount of labor hours both per acre and per bushel increased. Trends for wheat are somewhat different than for corn and soybeans for several reasons. One is a lower rate of yield improvement along with a relatively high implied-abandonment level for wheat. The low ratio of harvested to planted area for wheat is due to multiple factors, such as including wheat planted as a cover crop, wheat planted for pasture, and wheat being traditionally grown in drought-prone areas.

Discussion and Conclusions

This report explores broad-scale progress over time related to the major challenges facing agriculture in the 21st century: increasing demand, limited resources, and the need to maintain economically viable production systems that are consistent with the well-being of farmers and their communities. Such analyses of socioeconomic outcomes complement the analyses of environmental outcomes, and help us to better evaluate the sustainability implications of various trends in markets and production practices, such as the substitution of chemical and mechanical inputs, volatile product prices, government support mechanisms, and the use of alternative business arrangements such as leasing and contracting.

The economic indicators are driven in part by farming costs and revenues. While these indicators are affected by a multitude of variables in the agricultural industry—including macro and micro economic trends and federal support mechanisms—farmers have greater direct control over their costs than their revenues and continuously seek to improve in efficiency of all inputs.

The social indicators presented here show a decline in the number of labor hours, fatalities, and injuries on farm. Driven by productivity and harvesting efficiency gains, workers are spending less time in the field. These gains in return are driven by advances in farming equipment, technologies, and the adoption of conservation tillage practices that have all contributed to reduced tractor operation hours. The incorporation and improvement of GPS equipment and precision agriculture technologies, including improved safety mechanisms, have also contributed to the decrease in worker injury due to operator fatigue. It is interesting to note that the Labor Productivity indicator for many crops has plateaued in recent years; this coincides with a similar plateauing trend in the environmental indicators for some crops, and may represent together an indication that adoption of new practices and equipment for tillage, a driving force for both trends, has stabilized. While precision agriculture advances have increased the amount of work a single farmer can accomplish, other trends have potentially increased labor needs. In particular, in recent years as some CRP land is returned to active cultivation, and as herbicide-resistant weeds have become more prevalent, increases in plowing and tillage operations require additional labor to manage.

Capacity to continue and enhance these kinds of analyses is dependent on the availability of the public data sources upon which this report heavily relies. Public, national-level datasets provide a transparent, accessible, and fundamental means of understanding sustainability trends. Through this report and Field to Market's advancement of agricultural sustainability metrics and tools at a variety of scales, the Alliance seeks to enable an outcomes-based, science-based discussion on the definition, measurement, and advancement of sustainability. The intent is that such approaches will ultimately inform mechanisms to promote economically and socially viable improvements at the field level that contribute, in turn, to continued, significant, and broad-scale progress toward meeting sustainability challenges for production, resource use and impacts, and social and economic well-being.

Appendices

APPENDIX A: REFERENCES

[1] Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber et al. 2011. Solutions for a cultivated planet. Nature. DOI:10.1038/nature10452.

[2] Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, S Polasky. 2002. Agricultural sustainability and intensive production practices. Nature 418, 671-677. DOI:10.1038/nature01014.

[3] Robertson, G.P. 2015. A Sustainable Agriculture? Daedalus. DOI: 10.1162/DAED_a_00355.

[4] IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. R.K. Pachauri and L.A. Meyer (eds.) IPCC, Geneva, Switzerland, 151 pp.

[5] Macfadyen, S., J.M. Tylianakis, D.K. Letourneau, T.G. Bento, P. Tittonell, et al. 2016. The role of food retailers in improving resilience in global food supply. Global Food Security. DOI: /10.1016/j.gfs.2016.01.001.

[6] Tilman, D., C. Balzer, J. Hill, B.L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences. 108(50): 20260-20264.

[7] Godfray, H.C.J., T. Garnett. 2014. Food security and sustainable intensification. Philosophical Transactions of the Royal Society. B. 369: 20120273. DOI:10.1098/rstb.2012.0273.

[8] Cassman, K.G., A. Dobermann, D.T. Walters, H. Yang. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environmental and Resources. 28:315-358. DOI: 10.1146/annurev.energy.28.040202.122858.

[9] Grassini P., K.G. Cassman. 2012. High yield maize with large net energy yield and low global warming potential. Proceedings of the National Academy of Sciences. 109:1074-1079.

[10] West, P.C., J.S. Gerber, P.M. Engstrom, N.D. Mueller, K.A. Brauman et al. 2014. Leverage points for improving global food security and the environment. Science. 345(6194): 325-328.

[11] Wade, T., R Claassen, S Wallander. 2015. Conservation practice adoption rates vary widely by crop and region. USDA ERS Economic Information Bulletin Number 147. December 2015, 40pp.

[12] Lal, R., 2015. A systems approach to conservation agriculture. Journal of Soil and Water Conservation. DOI:10.2489/jswc.70.4.82A.

[13] Field to Market, 2012. Environmental and Socioeconomic Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States (Version 2) December, 2012. Available from: www.fieldtomarket.org.

[14] Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences. 104(33): 13268-13272. DOI: 10.1073/pnas.0611508104

[15] Field to Market, 2016. Exploring Opportunities to Advance Soil Health: The role of commodity crop supply chains in maintaining and improving the health of our nation's soil. Available from www.fieldtomarket.org.

[16] USDA. 2004. Briefing Room; Irrigation and Water Use. Washington, D.C.: United States Department of Agriculture.

[17] Grassini P., J. Specht, T. Tollenaar, I. Ciampitti, K.G. Cassman. 2014. High-yield maize-soybean cropping systems in the U.S. Corn Belt. In: Crop Physiology – Applications for genetic improvement and agronomy (2nd edition), Sadras V.O., Calderini D.F. (Eds). Elsevier, The Netherlands.

[18] Moore, B.C., A.M. Coleman, M.S. Wigmosta, R.L. Skaggs, E.R. Venteris. 2015. A high spatiotemporal assessment of consumptive water use and water scarcity in the conterminous United States. Water Resource Management. DOI: 10.1007/s11269-015-1112-x.

[19] Marshall, E., M. Aillery, S. Malcolm, R. Williams. 2015. Climate Change, Water Scarcity and Adaptation in the U.S. Fieldcrop Sector. USDA ERS. Economic Research Report 201, November 2015. Washington DC.

[20] Konikow, L.F. 2014. Long-term groundwater depletion in the United States. Groundwater. 53(1): 2-9.

[21] Gonzalez-Alvarez, Y., A.G. Keeler, J.D. Mullen. 2006. Farm-level irrigation and the marginal cost of water use: Evidence from Georgia. Journal of Environmental Management. 80:311-317.

[22] Khan, S., M.A. Hanjra. 2008. Sustainable land and water management policies and practices: A pathway to environmental sustainability in large irrigation systems. Land Degradation and Development 19:469.

[23] Piringer, G., L. Steinberg. 2006. Reevaluation of energy use in wheat production in the United States. Journal of Industrial Ecology. 10:1-2: 149-167.

[24] Shapouri, H., J. Duffield, A. McAloon, M. Wang. 2004. The 2001 net energy balance of corn-ethanol. Washington, D.C.: United States Department of Agriculture. https://www.ars.usda.gov/research/publications/publication/?seqNo115=161244.

[25] West, T.O., G. Marland. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. Agriculture, Ecosystems, and Environment. 91:217-232.

[26] Lal, R. 2004. Carbon emission from farm operations. Environmental International. 30 (2004) 981-990. http://dev.agroclimate.org/tools/calculations_tools/CarbonFootprint/references/Lal_2004.pdf.

[27] Hitaj, C., S. Suttles. 2016. Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass. USDA ERS. Economic Information Bulletin 159. 53pp. August 2016.

[28] U.S. EPA, 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. EPA 430-R-16-002. U.S. EPA, Washington DC. April 15, 2016.

[29] Grassini, P., J. Specht, T. Tollenaar, I. Ciampitti, K.G. Cassman. 2014. High-yield maize-soybean cropping systems in the U.S. Corn Belt. In: Crop Physiology – Applications for genetic improvement and agronomy (2nd edition), Sadras VO, Calderini DF (Eds). Elsevier, The Netherlands.

[30] Specht, J.E., B.W Diers, R.L. Nelson, J.F. Toledo et al. 2014. Soybean (Glycine max (L.) Merr.). In: Smith JSC, Carver B, Diers BW, Specht JE (Eds.), Yield Gains in Major U.S. Field Crops: Contributing Factors and Future Prospects. CSSA Special Publication #33, ASA-CSSA-SSSA, Madison, WI.

[31] Field to Market, 2009. Environmental and Socioeconomic Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States (First Report). January 2009. Available from: www.fieldtomarket.org.

[32] USDA, 2015. Summary Report: 2012 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 210 pages. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd396218.pdf.

[33] USDA ERS, 1992. Weights, Measures, and Conversion Factors for Agricultural Commodities and Their Products. Economic Research Service in cooperation with the Agricultural Marketing Service, the Agricultural Research Service, and the National Agricultural Statistics Service, U.S. Department of Agriculture. Agricultural Handbook No. 697.

[34] Roth, G.W., A.J. Heinrichs. 2001. Corn Silage Production and Management. Pennsylvania State University Extension. Agronomy Facts, 18.

[35] Ali, M.B. 2002. Characteristics and Production Costs of U.S. Wheat Farms. USDA Statistical Bulletin 974-5. July 2002.

[36] USDA NASS. 2016. National Agricultural Statistics Service Quick Stats 2.0 Database. All data accessed June-August 2016. https://quickstats.nass.usda.gov/.

[37] USDA NASS. 2016. Understanding Agricultural Statistics. https://www.nass.usda.gov/Education_and_Outreach/Understanding_Statistics/index.php. Accessed October 2016.

[38] USDA ARS. 2010. Overview of RUSLE2. Definitions and How RUSLE2 Computes sections. Online documentation (http://www.ars.usda.gov/Research/docs.htm?docid=6010).

[39] Pittlekow, C.M., X. Liang, B.A. Linquist, et al. 2014. Productivity limits and potential of the principles of conservation agriculture. Nature 517, 365-368

[40] USDA NASS. 1992. 1994 Farm & Ranch Irrigation Survey. In: Census of Agriculture 1992. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. https://www.agcensus.usda.gov/Publications/1992/Farm_and_Ranch_Irrigation_Survey/.

[41] USDA NASS. 1997. 1998 Farm & Ranch Irrigation Survey. In: Census of Agriculture 1997. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. https://www.agcensus.usda.gov/Publications/1997/Farm_and_Ranch_Irrigation_Survey/.

[42] USDA NASS. 2003. 2003 Farm & Ranch Irrigation Survey. In: Census of Agriculture, 2002. Washington, DC.: United States Department of Agriculture, National Agricultural Statistics Service

[43] USDA NASS. 2009. 2008 Farm & Ranch Irrigation Survey. In: United States Department of Agriculture, National Agricultural Statistics Service (NASS), Research and Development Division, Geospatial Information Branch, Spatial Analysis Research Section. 2009. 2007 Census of Agriculture, United States Summary and State Data.

[44] USDA NASS. 2014. 2013 Farm & Ranch Irrigation Survey. In 2012 Census of Agriculture. Available from https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

[45] IFA Technical Committee, 2009. Energy Efficiency and CO_2 Emissions in Ammonia Production. International Fertilizer Industry Association Feeding the Earth series. December 2009, Paris, France.

[46] USDA ERS, 2016. ARMS Farm Financial and Crop Production Practices Database. All data accessed June-August 2016. http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/tailored-reports-crop-production-practices.aspx.

[47] USDA NASS, 2016. Agricultural Chemical Usage Report. Online data for all crops after 2009. All data accessed June-August 2016. https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use/.

[48] ANL, 2011. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. Data tables for GREET 1.8d, Version 2011. Argonne National Laboratory and University of Chicago.

[49] Audsley, E., K. Stacey, D.J. Parsons, A.G. Williams. 2009. Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. https://dspace.lib.cranfield.ac.uk/bitstream/1826/3913/1/Estimation_of_the_greenhouse_gas_emissions_from_agricultural_pesticide_manufacture_and_use-2009.pdf.

[50] CTIC. 2006. 2006 Crop Residue Management Survey: A survey of tillage system usage by crops and acres planted. West Lafayette, IN: Purdue University Conservation Technology Information Center. http://www.conservationinformation.org/pdf/2006CRMSurveySummaryLoRes.pdf.

[51] USDA NRCS, 2016. NRCS Energy Estimator. Energy Consumption Awareness Tool: Tillage. Accessed June-August 2016. http://ecat.sc.egov.usda.gov/.

[52] Patterson, P.E., R.L. Smathers. 2006. 2006 Cost of Potato Production Comparisons for Idaho Commercial Potato Production, http://www.cals.uidaho.edu/aers/PDF/AEES/2006/AEES06-05.pdf.

[53] Sanford, S. 2005. Wisconsin Focus on Energy/Rural Energy Issues, University of Wisconsin, Biological Systems Engineering. Reduce Grain Drying Costs this Fall. http://extension.missouri.edu/seregion/Farm_Managenment/Wisconsin_Grin_Drying_Ecoonomics.pdf.

[54] U.S. EPA. 2008. Climate Leaders: Greenhouse Gas Inventory Protocol Core Module Guidance: Direct Emission from Mobile Combustion Sources. http://www.epa.gov/climateleadership/documents/resources/mobilesource_guidance.pdf.

[55] Cundiff, J.S. 2009. Curing quality peanuts in Virginia. Virginia Cooperative Extension paper 442-062. https://pubs.ext.vt.edu/442/442-062/442-062.html.

[56] USDA NASS 1990-2015. Crop Production [Year] Summary and Agricultural Chemical Usage Survey. Available as annual reports for Field Crops and Potatoes from: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1560.

[57] Nebraska Tractor Test Laboratory, University of Nebraska, Lincoln. http://tractortestlab.unl.edu/. Accessed June 2016.

[58] IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Ding, Y., Griggs, D.G., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K., C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

[59] Snyder, C.S., T.W. Bruulsema, T.L. Jensen, P.E. Fixen. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture Ecosystems and Environment. 133: 247–266.

[60] Bouwman, A.F., L.J.M. Boumans, N.H. Batjes. 2002. Modeling global annual N_2O and NO emissions from fertilized fields. Global Biogeochemical Cycles. 16:4:1080.

[61] Shcherbak, I.N., Millar, P. Robertson. 2014. Global metaanalysis of the nonlinear response of soil nitrous oxide (N_2O) emissions to fertilizer nitrogen. Proceedings of the National Academy of Sciences. DOI: 10.1073/pnas.1322434111

[62] IPCC. 2007a. Intergovernmental Panel on Climate Change: Fourth Assessment Report: Climate Change 2007 (AR4). www.ipcc.ch/publications_and_data/publications_and_data_reports.htm#1.

[63] Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

[64] Sleeter, B.M., T.S. Wilson, W. Acevedo (eds.) 2012. Status and trends of land change in the Western United States—1973 to 2000: U.S. Geological Survey Professional Paper 1794–A, 324 pp. Available at http://pubs.usgs.gov/pp/1794/a/.

[65] Taylor, J.L., W. Acevedo, R.F Auch, M.A. Drummond (eds.) 2015. Status and trends of land change in the Great Plains of the United States—1973 to 2000: U.S. Geological Survey Professional Paper 1794–B, 180 pp. DOI:10.3133/pp1794B.

[66] Auch, R.F., K.A. Karstensen (eds.) 2015. Status and trends of land change in the Midwest–South Central United States—1973 to 2000: U.S. Geological Survey Professional Paper 1794–C, 190 pp. DOI:10.3133/pp1794C.

[67] USGS, 2016. Status and Trends of land change in the Eastern U.S. – 1973-2000. http://pubs.usgs.gov/pp/1794/index.html. Accessed June 2016.

[68] USDA National Agricultural Statistics Service Cropland Data Layer. 2016 Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/. USDA-NASS, Washington, DC.

[69] Loveland, T.R., T.L. Sohl, S.V. Stehman, A.L. Gallant, K.L. Sayler, K.L., D.E. Napton. 2002, A strategy for estimating the rates of recent United States land cover changes. Photogrammetric Engineering and Remote Sensing. 68(10): 1091–1099.

[70] Johnston, C.A. 2014. Agricultural expansion: land use shell game in the U.S. Northern Plains. Landscape Ecology. 29:81-95. DOI: 10.1007/s10980-013-9947-0.

[71] Lark, T.J., J.M. Salmon, H.K. Gibbs. 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environmental Research Letters. 10:4. DOI:10 044003.

[72] Mladenoff, D.J., R. Sahajpal, C.P. Johnson, D.E. Rothstein. 2016. Recent land use change to agriculture in the U.S. lake states: Impacts on cellulosic biomass potential and natural lands. PLoS ONE. DOI:10.1371/journal.pone.0148566.

[73] Plourde, J.D., B.C. Pijanowski, B.K. Pekin. 2013. Evidence for increased monoculture cropping in the Central United States. Agriculture, Ecosystems and Environment. 165(2013): 50-59.

[74] Wright, K.W., M.C. Wimberly. 2013. Recent land use change in the Western Corn Belt threatens grassland and wetlands. Procedings of the National Academy of Sciences. DOI:10.1073/pnas.1215404110.

[75] Gage, A.M., S.K. Olimb, J. Nelson. 2016. Plowprint: Tracking cumulative cropland expansion to target grassland conservation. Great Plains Research *(in press)*.

[76] Larsen, A.E., B.T. Hendrickson, N. Dedeic, A.J. MacDonald. 2015. Taken as a given: Evaluating the accuracy of remotely sensed crop data in the USA. Agricultural Systems. 141:121-125.

[77] Reitsma, K.D., D.E. Clay, S.A. Clay, B.H. Dunn, C. Reese. 2016. Does the U.S. Cropland Data Layer provide an accurate benchmark for land-use change estimates?. Agronomy Journal. 108:266-272. DOI: 10.2134/agronj2015.0288.

[78] Johnson, D.M. 2013. A 2010 map estimate of annually tilled cropland within the conterminous United States. Agricultural Systems. 114: 95-105.

[79] Laingen, C. 2015. Measuring cropland change: A cautionary tale. Papers in Applied Geography. 1: 65-72. DOI: 10.1080/23754931.2015.1009305.

[80] Paustian, K., J. Lehmann, S. Ogle, D. Reay, G.P. Robertson, P. Smith. 2016. Climate-smart soils. Nature. 532:49-57. DOI:10.1038/nature17174.

[81] West, T.O., G. Marland, A.W. King, W.M. Post. 2003. Carbon management response curves: estimates of temporal soil carbon dynamics. Environmental Management. 33(4): 507-518. DOI: 10.1007/s00267-003-9108-3.

[82] Baker, J.M., T.J. Griffis. 2005. Examining strategies to improve the carbon balance of corn/soybean agriculture using eddy covariance and mass balance techniques. Agricultural and Forest Meteorology. 128: 163–177.

[83] Blanco-Canqui, H., R. Lal. 2008. No-tillage and soil-profile carbon sequestration: an on-farm assessment. Soil Science Society of America Journal. 72:693–701.

[84] Verma, S.B., A. Dobermann, K.G. Cassman et al. 2005. Annual carbon dioxide exchange in irrigated and rainfed maize-based agroecosystems. Agricultural and Forest Meteorology. 131: 77–96.

[85] USDA 2011. U.S. agriculture and forestry greenhouse gas inventory: 1990-2008. U.S. Department of Agriculture, Office of the Chief Economist, Climate Change Program Office. Technical Bulletin No. 1930. 159 pp., http://www.usda.gov/oce/climate_change/AFGG_Inventory/USDA_GHG_Inv_1990-2008_June2011.pdf.

APPENDICES

[86] Del Grosso, S.J., W.J. Parton, C.A. Keough, M. Reyes-Fox. 2011. Special features of the DayCent modeling package and additional procedures for parameterization, calibration, validation, and applications, in Methods of Introducing System Models into Agricultural Research, L.R. Ahuja and Liwang Ma (eds.) p. 155-176, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. USA.

[87] Parton, W.J., D.S. Ojima, C.V. Cole, D.S. Schimel. 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. Quantitative Modeling of Soil Farming Processes. Pp. 147-167. R.B. Bryand, and R.W. Arnold (eds.) Soil Science Society of America, Madison, WI.

[88] Follett, R.F. 2001. Soil management concepts and carbon sequestration in cropland soils. Soil and Tillage Research. 61:(1,2)77-92. DOI: 10.1016/S0167-1987(01)00180-5.

[89] Morgan, J.A., R.F. Follett, L.H. Allen, Jr., S.D. Grosso, et a.. 2010. Carbon sequestration in agricultural lands of the United States. Journal of Soil and Water Conservation, 65(1):6A-12A. DOI:10.2489/jswc.65.1.6A.

[90] Lal, H., S. McKinney. 2012 WQIag- Water Quality Index for Runoff Water from Agricultural Fields. USDA-NRCS publication. http://wqiag.sc.egov.usda.gov/.

[91] U.S. Department of the Interior, U.S. Geological Survey. 2015. Tracking Water Quality of the Nation's Rivers and Streams. Website, accessed July 2016. http://cida.usgs.gov/quality/rivers/home.

[92] Van Meter, K.J., N.B. Basu, J.J. Veenstra, C.L. Burras. 2016. The nitrogen legacy: emerging evidence of nitrogen accumulation in anthropogenic landscapes. Environmental Research Letters. 11(2016): 035014. DOI:10.1088/1748-9326/11/3/035014.

[93] Dubrovsky, N.M., K.R. Burow, et.al. 2010. Nutrients in the nation's streams and groundwater, 1992-2004. U.S. Geological Survey Circular 1350, p. 1-174.

[94] Murphy, J.C., R.M. Hirsch, L.A. Sprague. 2013. Nitrate in the Mississippi River and its tributaries, 1980–2010—An update: U.S. Geological Survey Scientific Investigations Report 2013–5169, 31 p., http://pubs.usgs.gov/sir/2013/5169/.

[95] Stets, E.G., V.J. Kelly, C.G. Crawford. 2015. Regional and temporal differences in nitrate trends discerned from long-term water quality monitoring data. Journal of the American Water Resources Association. 51(5):1394-1497.

[96] USDA. 2016. Conservation Effects Assessment Program Web portal: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/.

[97] Duriancik, L.F., D. Bucks, J.P. Dobrowolski, T. Drewes, S.D. Eckles, et al. 2008. The first five years of the Conservation Effects Assessment Project. Journal of Soil and Water Conservation, Nov.-Dec. 2008.

[98] Osmond, D.L., D.W. Meals, D.L.K. Hoag, M. Arabi, A.E. Luloff et al. 2012. Synthesizing the experience of the 13 National Institute of Food and Agriculture-Conservation Effects Assessment Project watershed studies: present and future. In: D.L. Osmond, et al. (eds) How to build better agricultural conservation programs to protect water quality: the National Institute of Food and Agriculture-Conservation Effects Assessment Project experience. Soil and Water Conservation Society, Ankeny, IA. p. 151-167.

[99] Tomer, M.D., M.A. Locke. 2011. The challenge of documenting water quality benefits of conservation practices: a review of USDA-ARS's conservation effects assessment project watershed studies. Water Science & Technology 64(1):300-310. DOI: 10.2166/wst.2011.555.

[100] Arnold, J.G., R. Srinivasan, R.S. Muttiah, J.R. Williams. 1998. Large area hydrologic modeling and assessment part I: model development. Journal of the American Water Resources Association. 34(1): 73-89.

[101] Arnold, J.G., R. Srinivasan, R.S. Muttiah, P.M. Allen. 1999. Continental scale simulation of the hydrologic balance. Journal of the American Water Resources Association. 35(5): 1037-1052.

[102] Gassman, P.W., J.R. Williams, S. Wang, A. Saleh, E. Osei, et al. 2009. The Agricultural Policy Environmental Extender (APEX) model: An emerging tool for landscape and watershed environmental analyses. Technical Report 09-TR 49. CARD, Iowa State Univ., Ames, IA. Available at: http://www.card.iastate.edu/publications/synopsis.aspx?id=1101.

[103] USDA, 2011. Chesapeake Bay: 2011. Assessment of the effects of conservation practices on cultivated cropland in the Chesapeake Bay Region. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042076.pdf.

[104] USDA, 2014. Delaware River Basin: 2014. Assessment of the effects of conservation practices on cultivated cropland in the Delaware River Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263627.pdf.

[105] USDA, 2014. South Atlantic Gulf Basin: 2014. Assessment of the effects of conservation practices on cultivated cropland in the South Atlantic Gulf Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1256674.pdf.

[106] USDA, 2011. Great Lakes Basin: 2011. Assessment of the effects of conservation practices on cultivated cropland in the Great Lakes Region. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1045480.pdf.

[107] USDA, 2011. Ohio-Tennessee River Basin: 2011. Assessment of the effects of conservation practices on cultivated cropland in the Ohio-Tennessee River Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046342.pdf.

[108] USDA, 2012. Upper Mississippi River Basin: 2012. Assessment of the effects of conservation practices on cultivated cropland in the Upper Mississippi River Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042093.pdf.

[109] USDA, 2013. Lower Mississippi River Basin: 2013. Assessment of the effects of conservation practices on cultivated cropland in the Lower Mississippi River Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1176978.pdf.

[110] USDA, 2014. Souris-Red-Rainy Basin: 2014. Assessment of the effects of conservation practices on cultivated cropland in the Souris-Red-Rainy Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1260130.pdf.

[111] USDA, 2012. Missouri River Basin: 2012. Assessment of the effects of conservation practices on cultivated cropland in the Missouri River Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1048710.pdf.

[112] USDA, 2013. Arkansas-White-Red River Basin: 2013. Assessment of the effects of conservation practices on cultivated cropland in the Arkansas-White-Red River Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1088485.pdf.

[113] USDA, 2015. Texas Gulf Basin: 2015. Assessment of the effects of conservation practices on cultivated cropland in the Texas Gulf Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd374812.pdf.

[114] USDA, 2014. Pacific Northwest: 2014. Assessment of the effects of conservation practices on cultivated cropland in the Pacific Northwest Basin. U.S. Department of Agriculture, Natural Resources Conservation Service. Conservation Effects Assessment Project CEAP, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1256682.pdf.

[115] Garcia, A.M., R.B. Alexander, J. Arnold, L. Norfleet, M.J. White, D. Robertson, and G.E. Schwarz. 2016. Regional effects of agricultural conservation practices on nutrient transport in the Upper Mississippi River Basin. Environmental Science & Technology. doi: 10.1021/acs.est.5b03543.

[116] USDA ERS. 2016. Commodity Costs and Returns: Data. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm. Accessed September 2016.

[117] USDA ERS. 2016. Agricultural Resources Management Survey. Washington, D.C.: USDA Economic Research Service. http://www.ers.usda.gov/briefing/ARMS. Accessed September 2016.

[118] USDA NASS. 2016. Crop Values 2015 Summary. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1050. Accessed September 2016.

[119] USDA ERS. 2016. Farm Household Well Being. http://www.ers.usda.gov/topics/farm-economy/farm-household-well-being.aspx. Accessed September 2016.

[120] USDA ERS. 2009. Farm Business and Household Survey Data- Farm Business Financial Ratio Report of Farm Finances Survey for all farms from 1996 to 2008. Accessed 2012

[121] USDA NASS, 2016. Agricultural Prices Reports. https://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1002. Accessed September 2016.

[122] U.S. Department of Commerce BEA. 2016. GDP and Personal Income. Washington, D.C.: U.S. Department of Commerce Bureau of Economic Analysis. http://www.bea.gov/iTable/iTable.cfm?ReqID=70&step=1&isuri=1&acrdn=1. Accessed September 2016.

[123] U.S. Bureau of Labor Statistics. 2016. Nonfatal occupational injuries and illnesses involving days away from work. Washington, DC, http://www.bls.gov/news.release/osh2.toc.htm. Accessed September 2016.

[124] U.S. Bureau of Labor Statistics. 2016. Washington, DC: United Sates Bureau of Labor Statistics. Census of Fatal Occupational Injuries. http://www.bls.gov/news.release/cfoi.toc.htm. Accessed September 2016.

[125] USDA NASS 2016. Farm Labor. ISSN: 1949-0909, Published 5-19-2016 by the USDA Agricultural Statistics Board. Washington, DC.

APPENDIX B: ADDITIONAL REPRESENTATIONS OF ENVIRONMENTAL INDICATORS

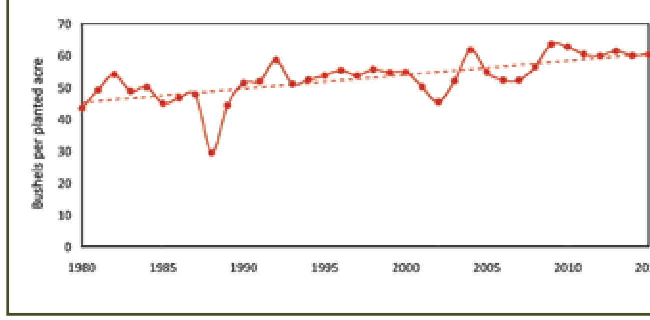
In addition to the primary sustainability indicators calculated and presented in Part One of this report, the resource use per acre for Land Use, Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions and the total resource use for Soil Conservation, Irrigation Water Use, Energy Use, and Greenhouse Gas Emissions were calculated. That information is provided here as a supplement to further explore trends in environmental sustainability for each crop.

Table B.1: List of Crops and Units of Production

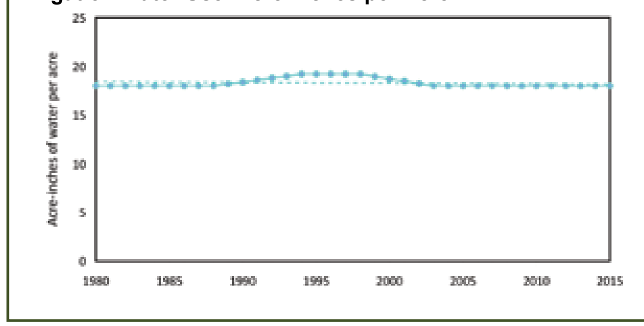
Crop	Yield Unit	Description
BARLEY	bu.	Bushel, 48 lb. of barley grain per bushel
CORN (GRAIN)	bu.	Bushel, 56 lb. of corn grain per bushel
CORN (SILAGE)	ton	2,000 lb.
COTTON	lb. of lint	Pounds (lb.) of lint
PEANUTS	lb.	Pounds (lb.)
POTATOES	cwt.	Hundred weight (100 lb.)
RICE	cwt.	Hundred weight (100 lb.)
SOYBEANS	bu.	Bushel, 60 lb. of soybean seed per bushel
SUGAR BEETS	ton	2,000 lb.
WHEAT	bu.	Bushel, 60 lb. of wheat grain per bushel

BARLEY

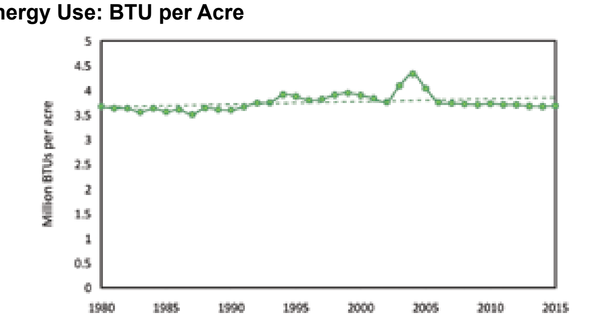
Land Use: Bushels per Planted Acre



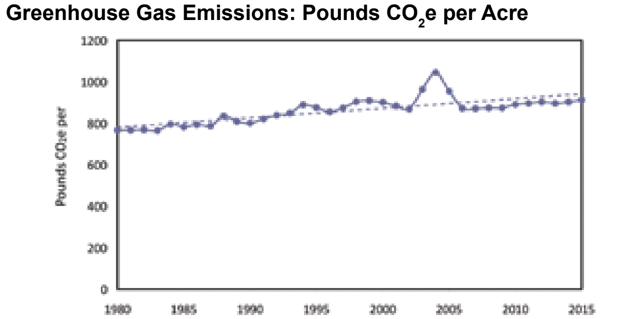
Irrigation Water Use: Acre-inches per Acre



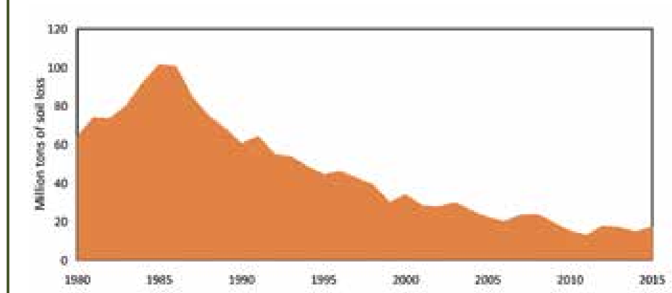
Energy Use: BTU per Acre



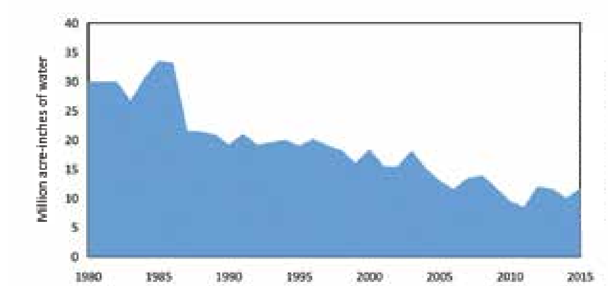
Greenhouse Gas Emissions: Pounds CO_2e per Acre



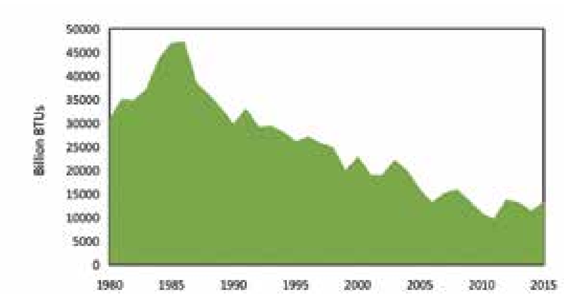
Soil Conservation: Million Tons of Soil Loss



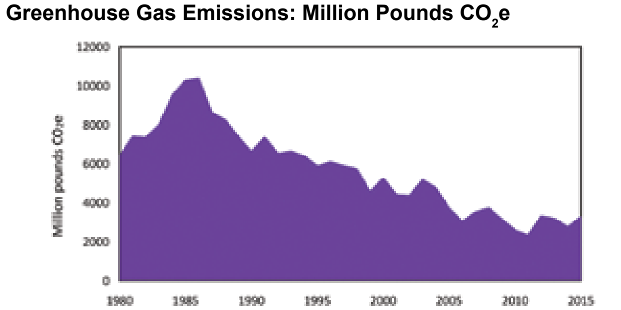
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU

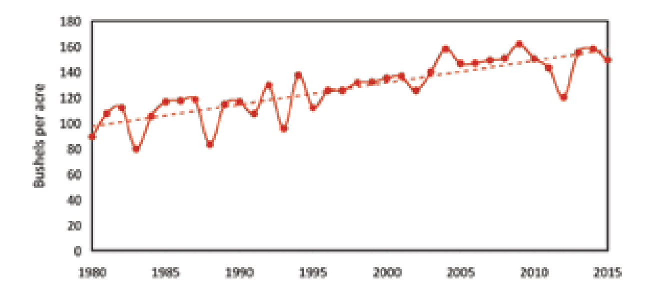


Greenhouse Gas Emissions: Million Pounds CO_2e

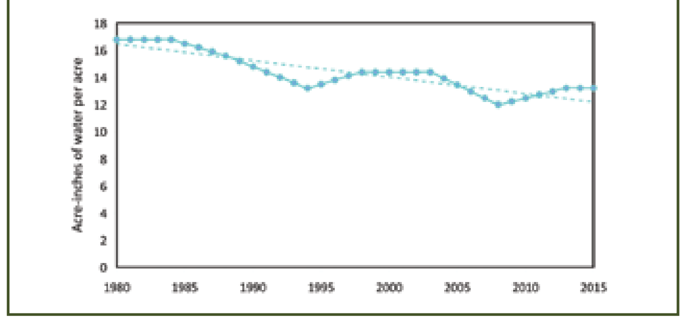


CORN FOR GRAIN

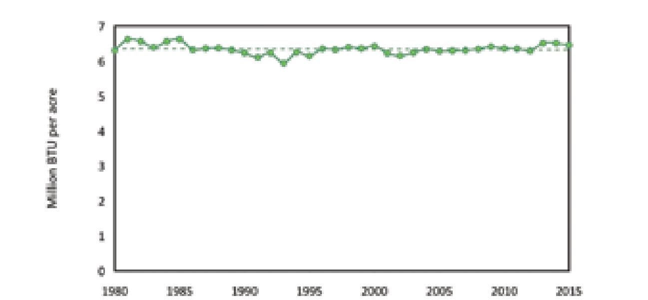
Land Use: Bushels per Planted Acre



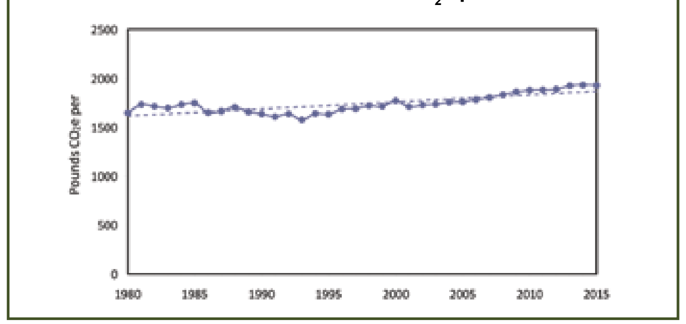
Irrigation Water Use: Acre-inches per Acre



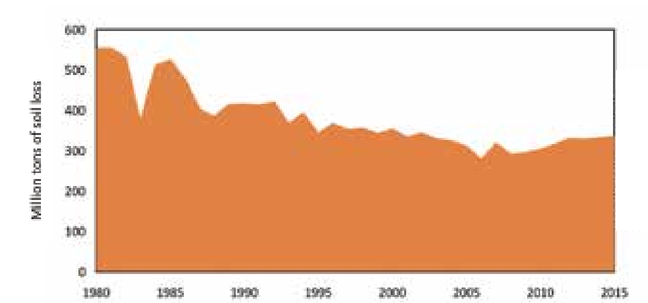
Energy Use: BTU per Acre



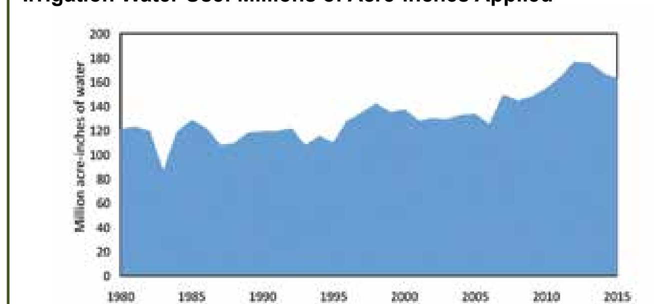
Greenhouse Gas Emissions: Pounds CO_2e per Acre



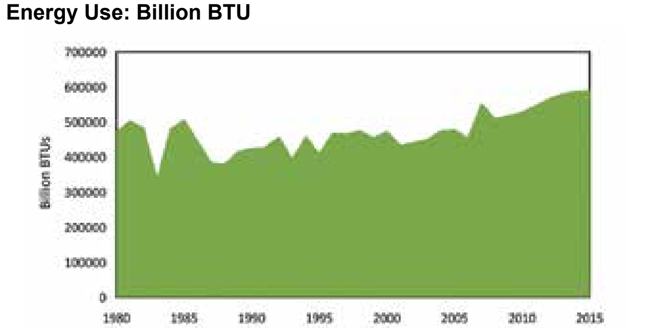
Soil Conservation: Million Tons of Soil Loss



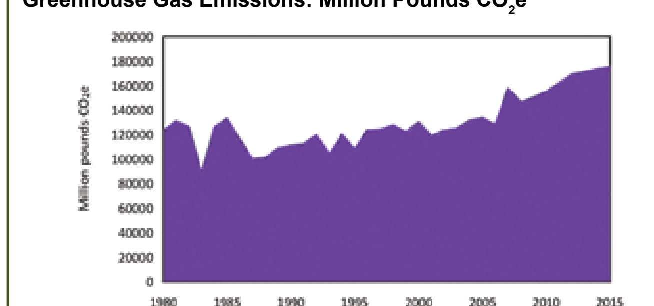
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU



Greenhouse Gas Emissions: Million Pounds CO_2e



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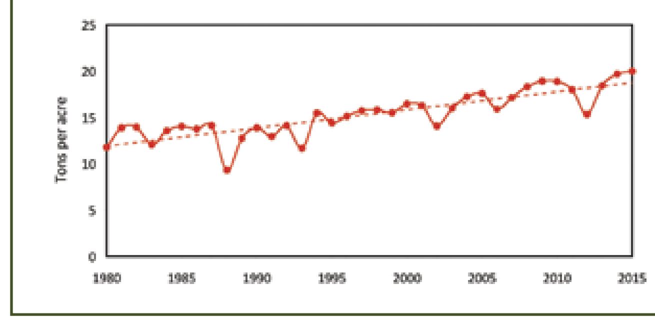
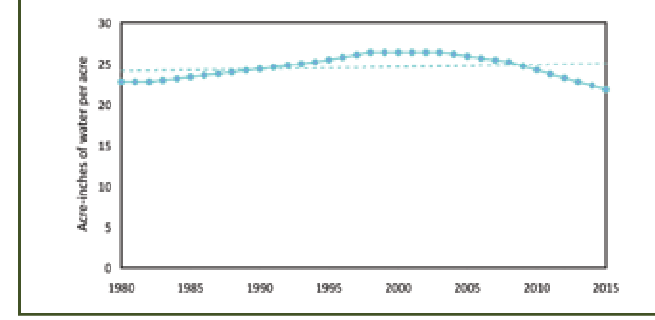
CORN FOR SILAGE

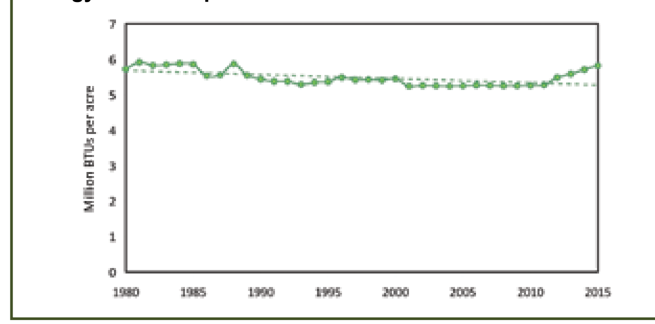
Land Use: Tons per Planted Acre



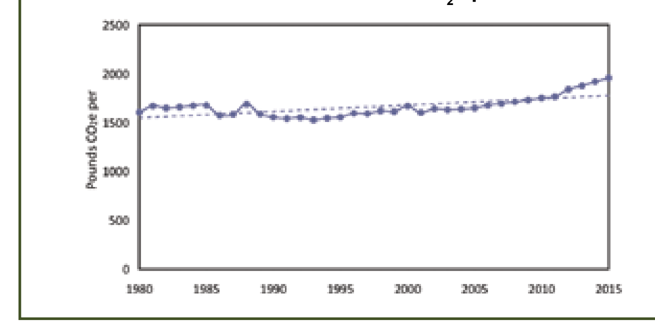
Irrigation Water Use: Acre-inches per Acre



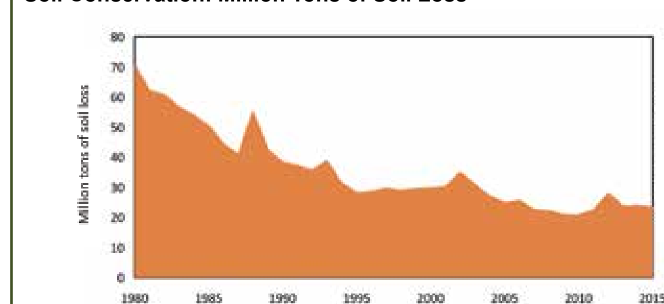
Energy Use: BTU per Acre



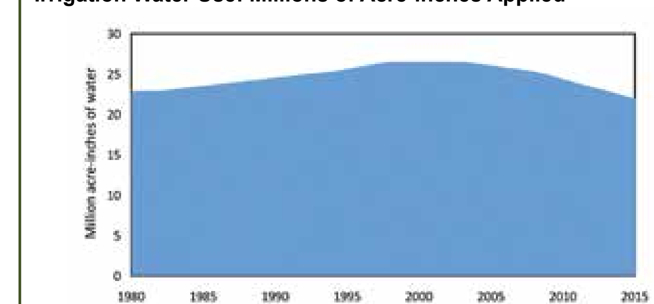
Greenhouse Gas Emissions: Pounds CO_2e per Acre



Soil Conservation: Million Tons of Soil Loss

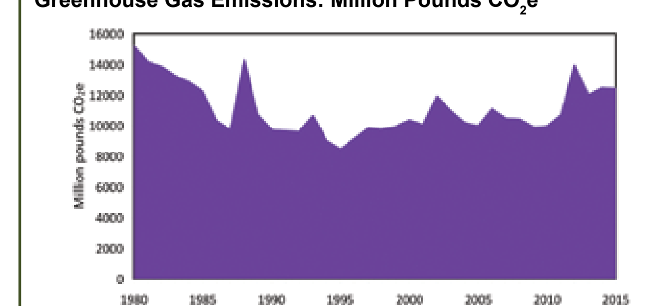


Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU

Greenhouse Gas Emissions: Million Pounds CO_2e



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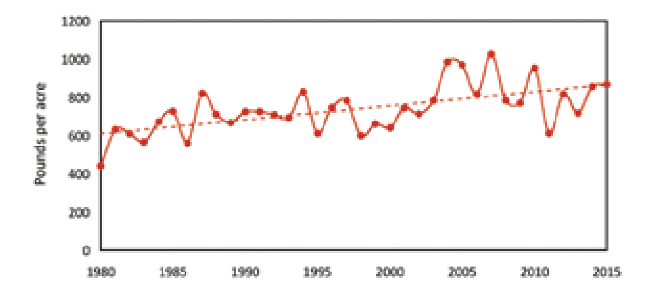
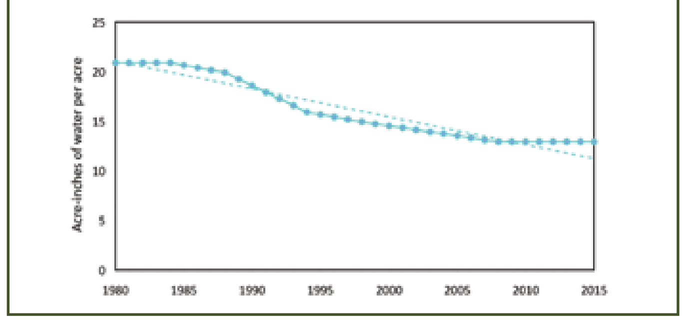
COTTON (LINT)

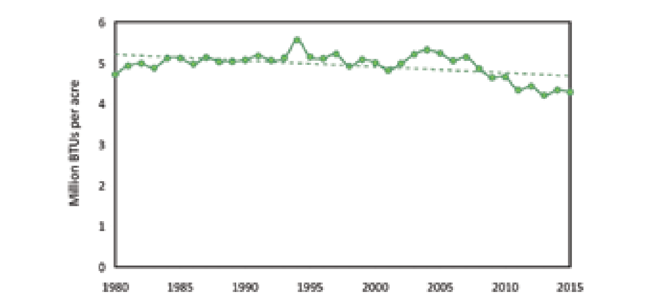
Land Use: Pounds per Planted Acre



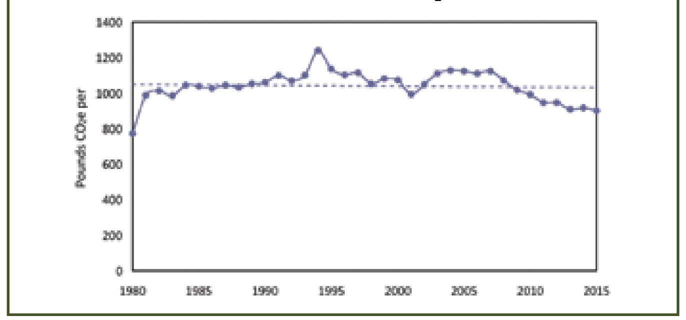
Irrigation Water Use: Acre-inches per Acre



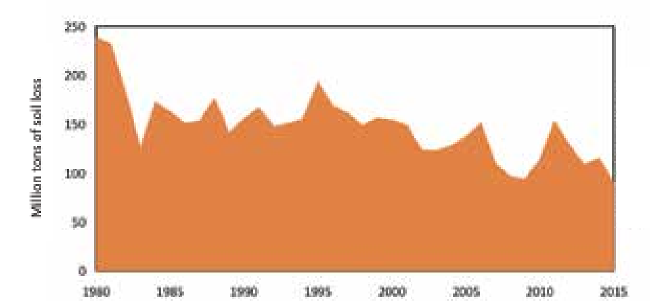
Energy Use: BTU per Acre



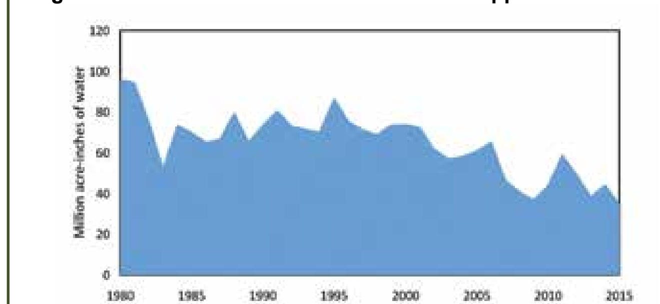
Greenhouse Gas Emissions: Pounds CO_2e per Acre



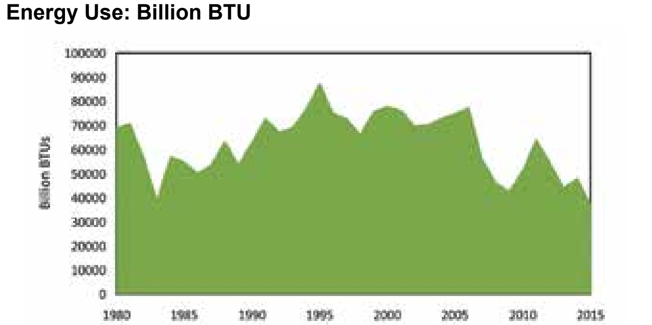
Soil Conservation: Million Tons of Soil Loss



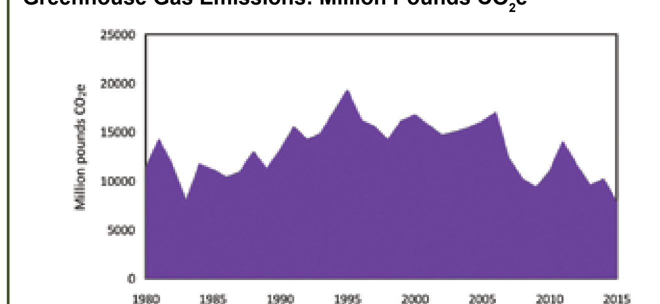
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU

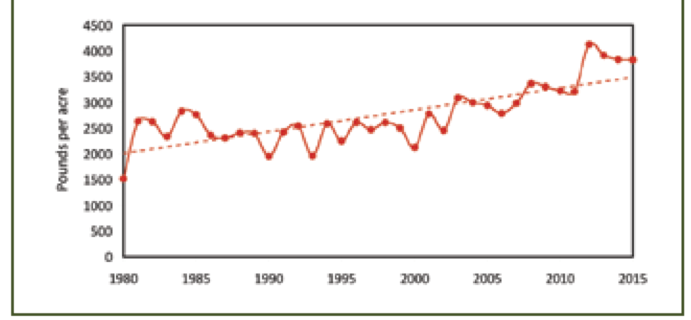


Greenhouse Gas Emissions: Million Pounds CO_2e

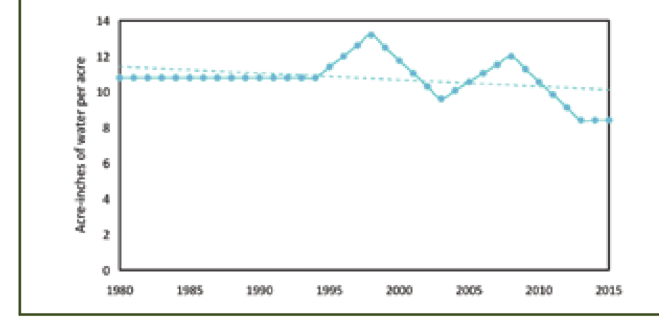


PEANUTS

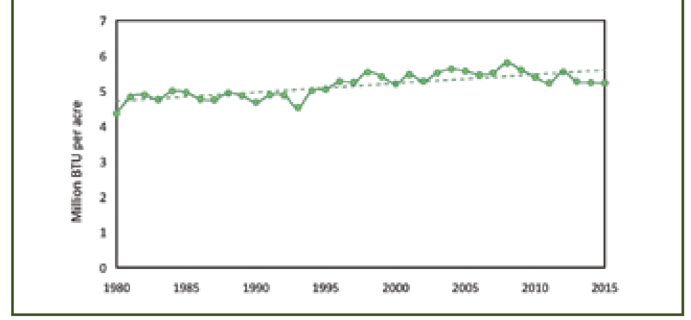
Land Use: Pounds per Planted Acre



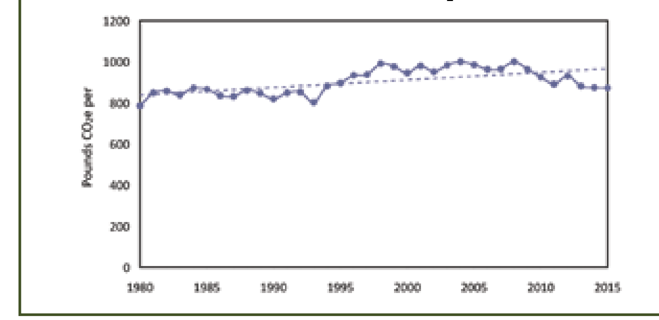
Irrigation Water Use: Acre-inches per Acre



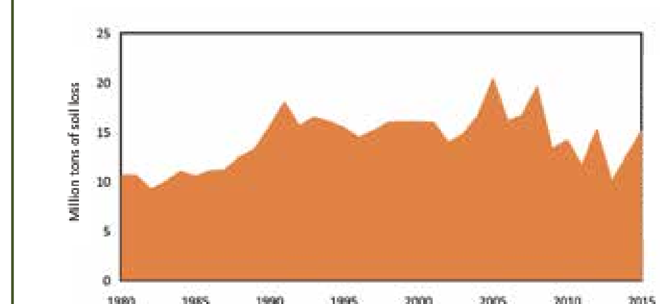
Energy Use: BTU per Acre



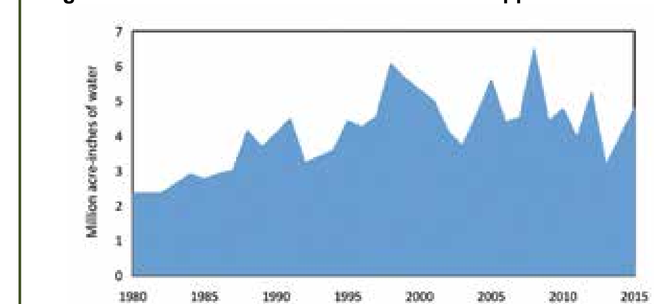
Greenhouse Gas Emissions: Pounds CO_2e per Acre



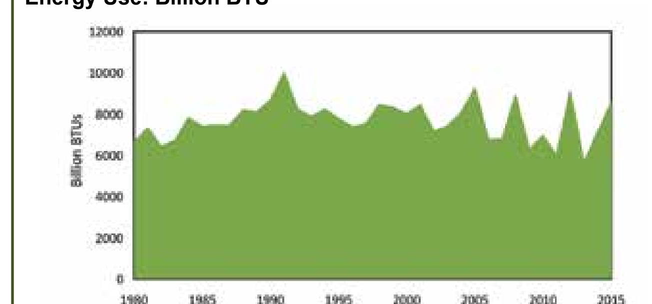
Soil Conservation: Million Tons of Soil Loss



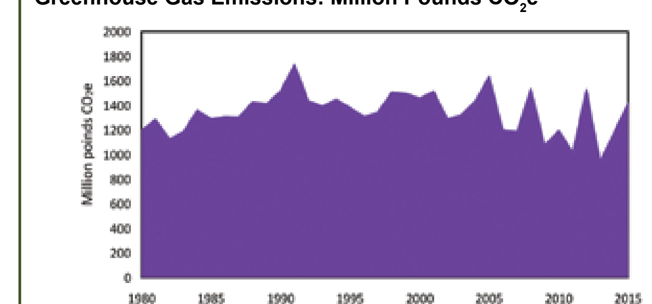
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU



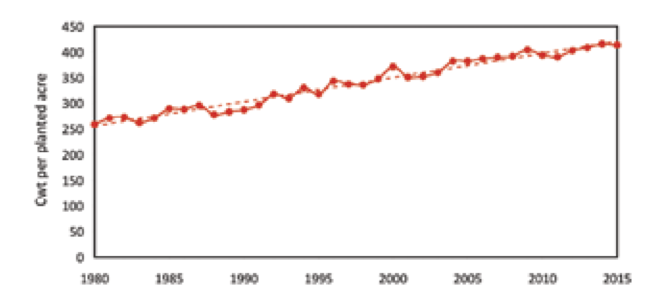
Greenhouse Gas Emissions: Million Pounds CO_2e



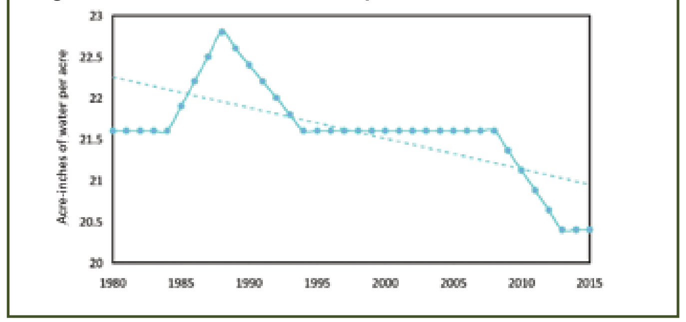
APPENDICES

POTATOES

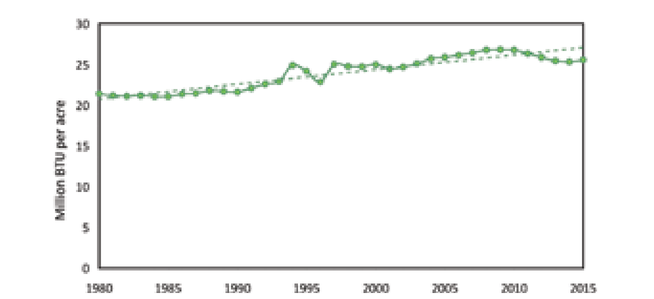
Land Use: Cwt. per Planted Acre



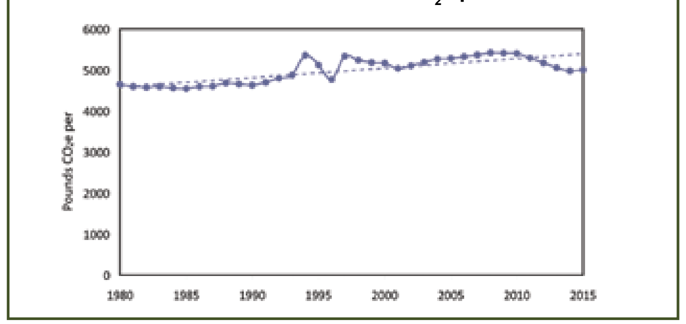
Irrigation Water Use: Acre-inches per Acre



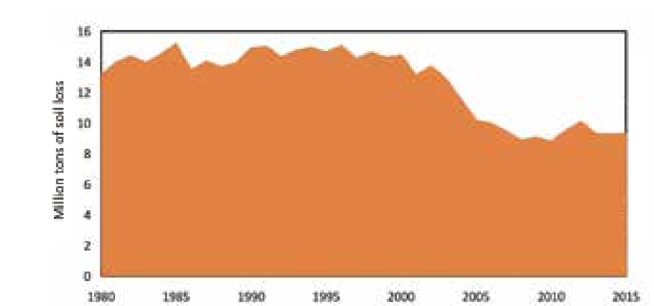
Energy Use: BTU per Acre



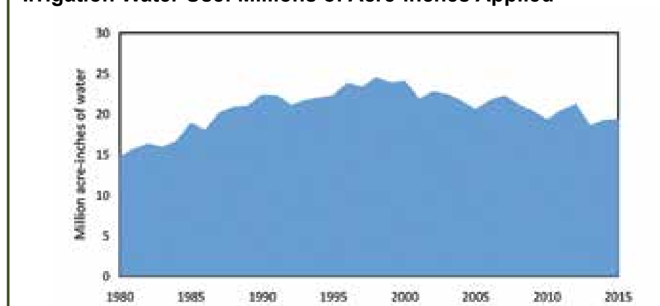
Greenhouse Gas Emissions: Pounds CO_2e per Acre



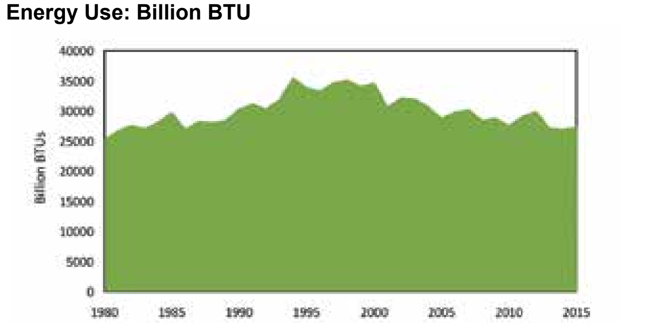
Soil Conservation: Million Tons of Soil Loss



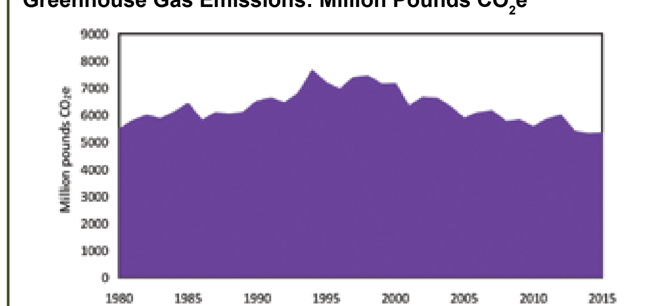
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU

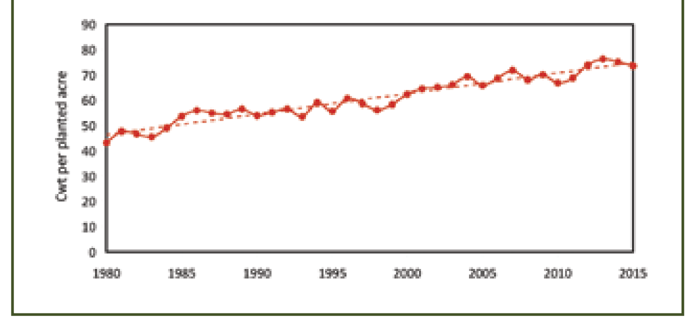


Greenhouse Gas Emissions: Million Pounds CO_2e

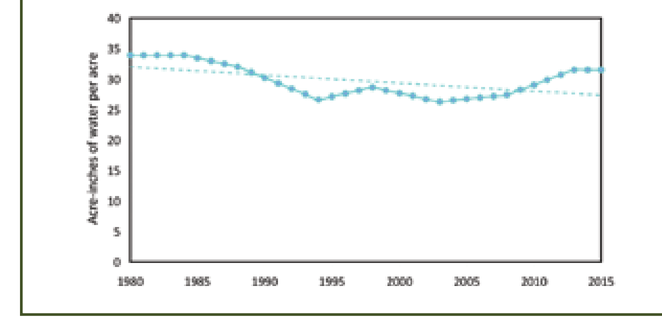


RICE

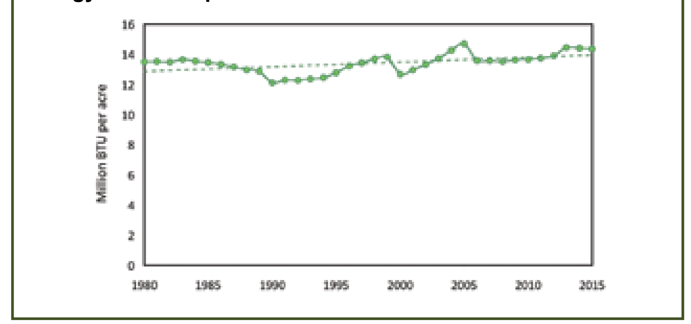
Land Use: Cwt. per Planted Acre



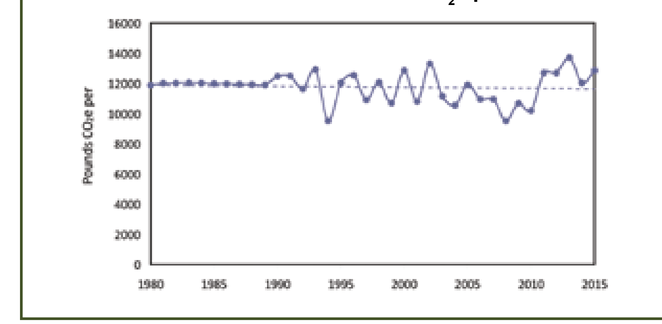
Irrigation Water Use: Acre-inches per Acre



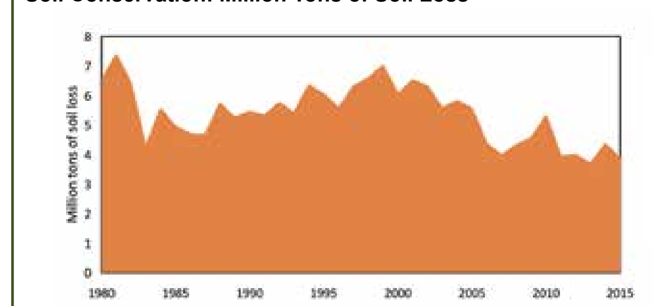
Energy Use: BTU per Acre



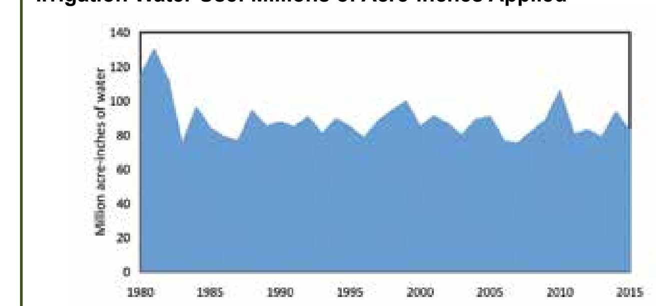
Greenhouse Gas Emissions: Pounds CO_2e per Acre



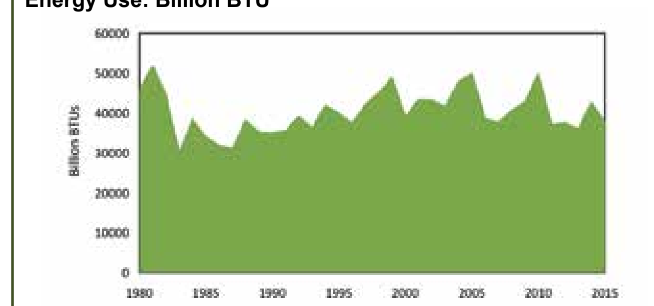
Soil Conservation: Million Tons of Soil Loss



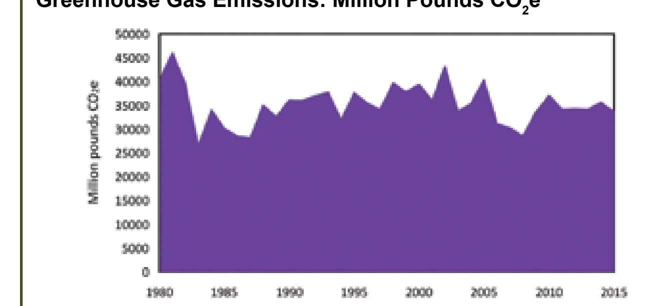
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU



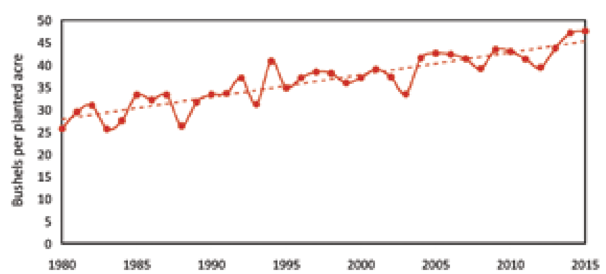
Greenhouse Gas Emissions: Million Pounds CO_2e



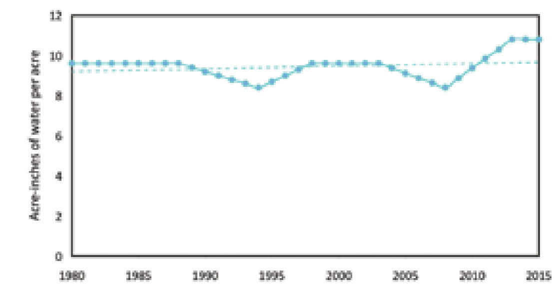
APPENDICES

SOYBEANS

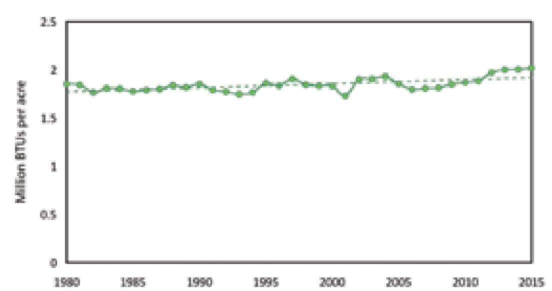
Land Use: Bushels per Planted Acre



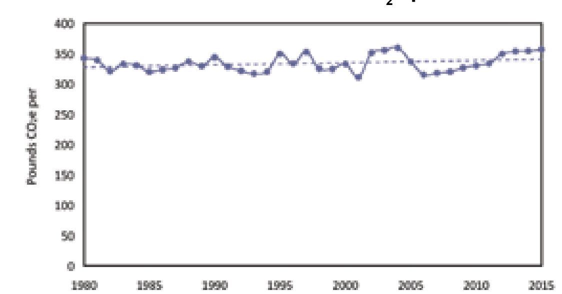
Irrigation Water Use: Acre-inches per Acre



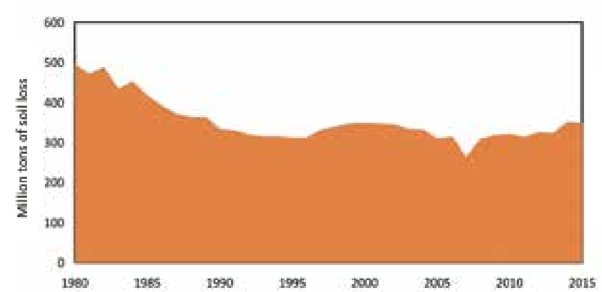
Energy Use: BTU per Acre



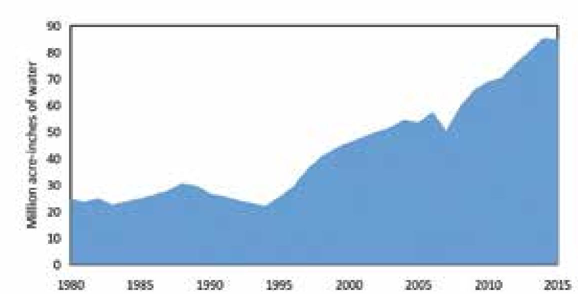
Greenhouse Gas Emissions: Pounds CO_2e per Acre



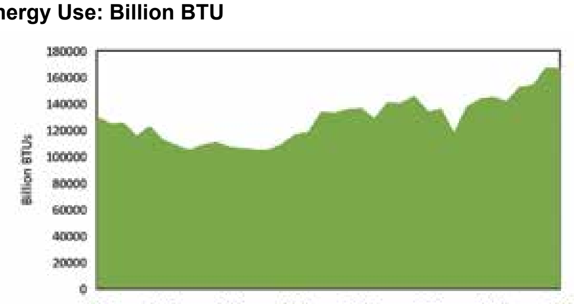
Soil Conservation: Million Tons of Soil Loss



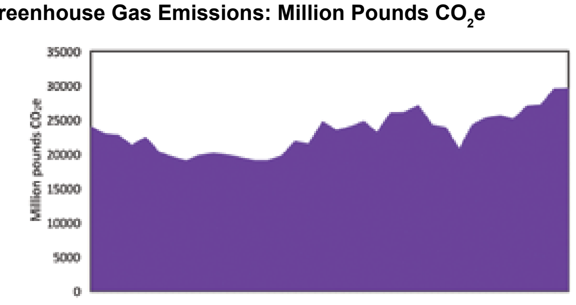
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU

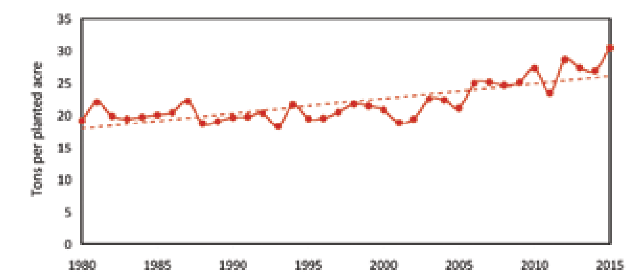


Greenhouse Gas Emissions: Million Pounds CO_2e

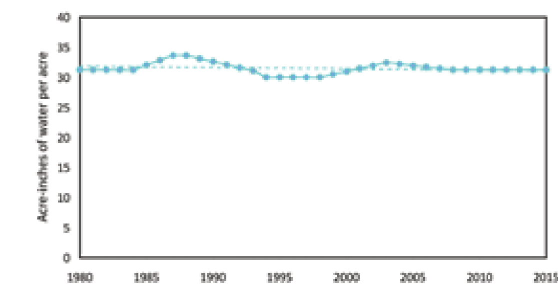


SUGAR BEETS

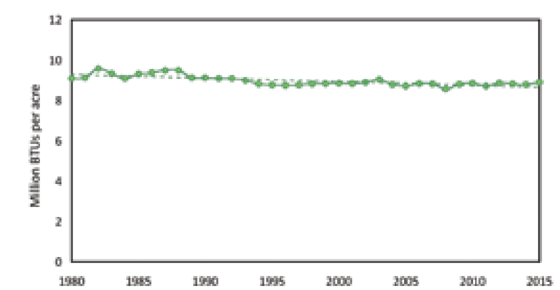
Land Use: Tons per Planted Acre



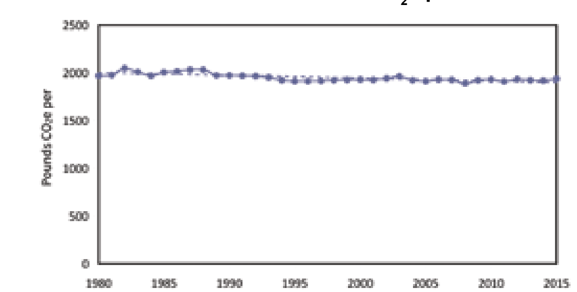
Irrigation Water Use: Acre-inches per Acre



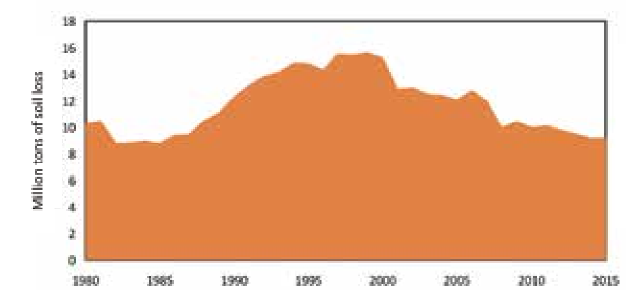
Energy Use: BTU per Acre



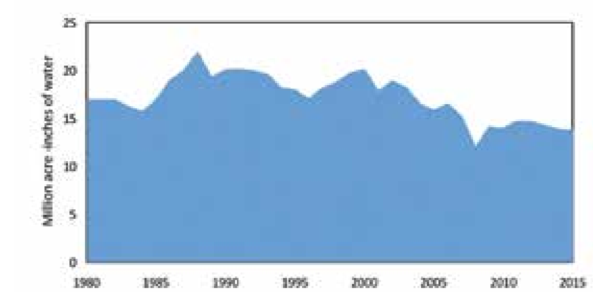
Greenhouse Gas Emissions: Pounds CO_2e per Acre



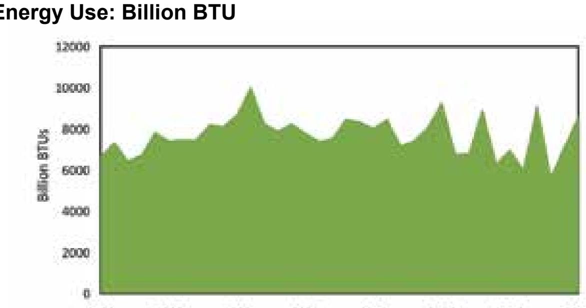
Soil Conservation: Million Tons of Soil Loss



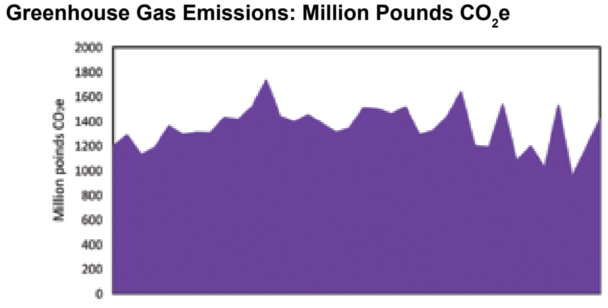
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU

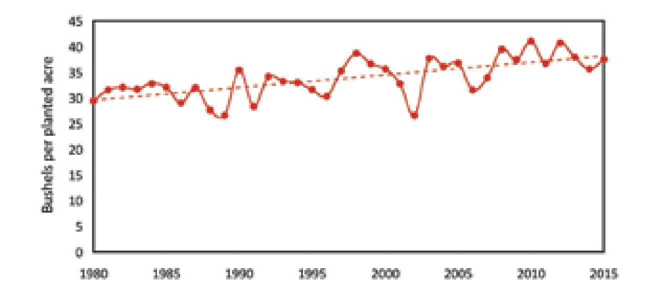


Greenhouse Gas Emissions: Million Pounds CO_2e

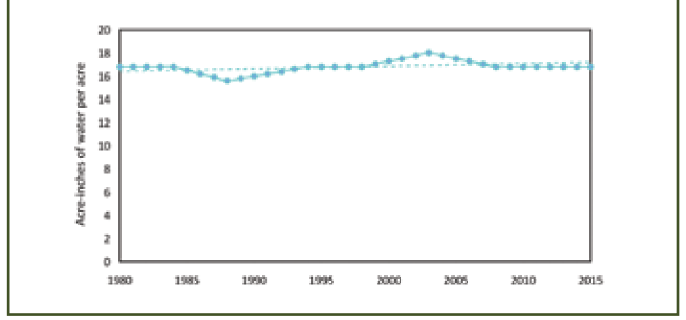


WHEAT

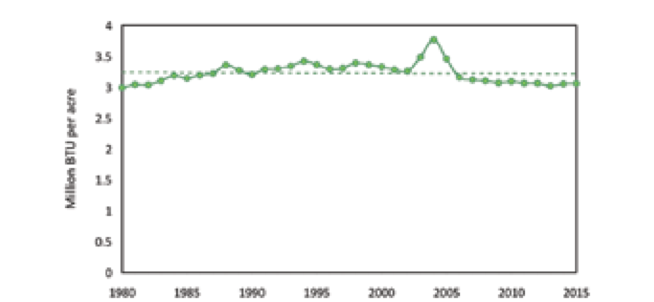
Land Use: Bushels per Planted Acre



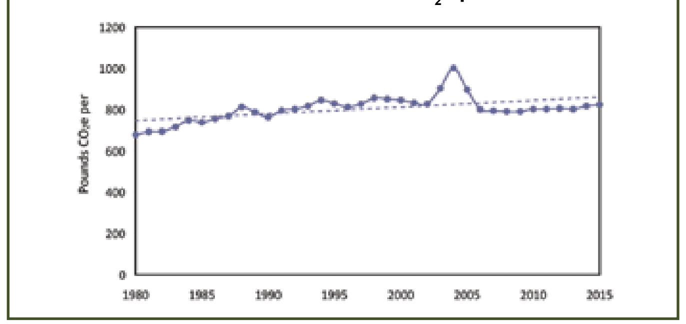
Irrigation Water Use: Acre-inches per Acre



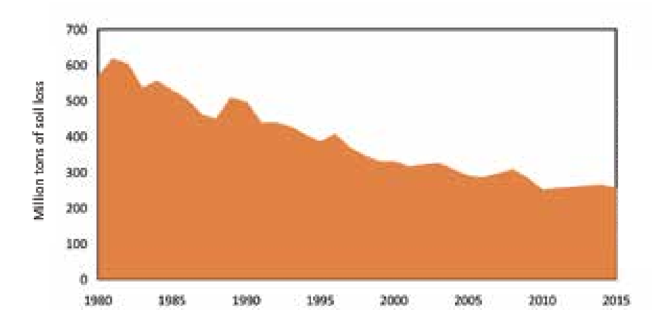
Energy Use: BTU per Acre



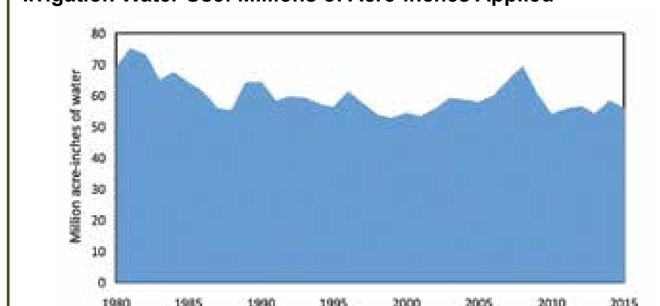
Greenhouse Gas Emissions: Pounds CO_2e per Acre



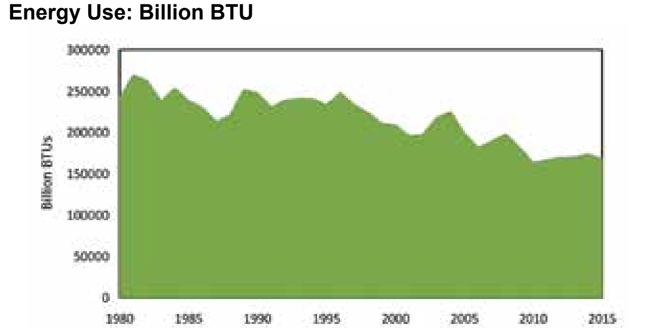
Soil Conservation: Million Tons of Soil Loss



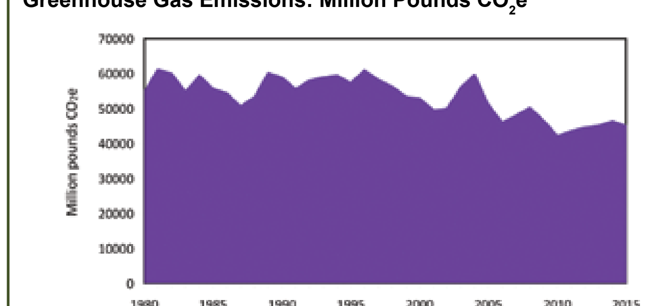
Irrigation Water Use: Millions of Acre-inches Applied



Energy Use: Billion BTU



Greenhouse Gas Emissions: Million Pounds CO_2e



APPENDICES

APPENDIX C: HOW TO CITE THIS REPORT

Field to Market: The Alliance for Sustainable Agriculture, 2016. Environmental and Socioeconomic Indicators for Measuring Outcomes of On Farm Agricultural Production in the United States (Third Edition). ISBN: 978-0-692-81902-9.

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