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

Second Report (Version 2), Revised December 2012

How to Cite this Report

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Note on this version: This report (Version 2, December 2012) replaces the report released in July 2012 (Field to Market (2012). Environmental and Socioeconomic Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States: Second Report, July 2012). This version corrects errors related to the energy and greenhouse gas results for corn, cotton, soybeans, and wheat. While the overall conclusions found in this report remain the same, this version contains new charts and data for total, per acre, per unit of output, and overall percent change values for these indicators and crops. The error in the July 2012 version of the report was related to the use of USDA ARMs data for average fertilizer (N,P,K) application rates for corn, cotton, soybeans, and wheat. Specifically, the rates used in the July 2012 report did not include the impact of the share of acres of these crops not treated with any fertilizer and instead assumed treatment of all planted acreage. Given that fertilizer use varies considerably across crops and that the proportion of treated acreage for a given crop also varies by year, the correction has different impacts for the revised results for each of the crops. For all crops, the revision results in a decrease in actual total, per acre, and per unit of output levels of energy use and greenhouse gas emissions. The impact of the correction on the average percent change trend for the full study period (1980 to 2011) was variable: the direction of change stayed the same in all but two instances (wheat energy use per acre and cotton emissions per acre) while rate of change increased in some instances and decreased in others.

Table of Contents

Acknowledgements

Field to Market is a collaborative stakeholder group of producers, agribusinesses, food, fiber and retail companies, conservation organizations, universities, and agency partners that are working together to define, measure, and develop a supply-chain system for agricultural sustainability. Field to Market member organizations provide oversight and technical guidance for the development of Alliance metrics and tools. Member organizations as of the date of this revised publication (December 2012) include:

- American Farm Bureau Federation
- American Soybean Association
- Bayer CropScience
- BASF
- Bunge
- Cargill
- CHS Inc.
- Conservation Technology Information Center
- Cotton Incorporated
- CropLife America
- CropLife International
- *Ducks Unlimited
- DuPont Pioneer
- Environmental Defense Fund
- Fleishman-Hillard
- General Mills
- Illinois Soybean Association
- Indiana Soybean Alliance
- International Plant Nutrition Institute
- Innovation Center for U.S. Dairy
- John Deere
- Kellogg Company
- Land O'Lakes
- Manomet Center for Conservation Sciences
- Monsanto Company
- National Alfalfa & Forage Alliance
- National Association of Wheat Growers
- National Corn Growers Association
- National Cotton Council of America
- National Potato Council
- Natural Resources Conservation Service (NRCS)
- North Carolina State University
- Penton Media
- The Fertilizer Institute
- The Coca-Cola Company
- The Nature Conservancy
- Syngenta Corporation
- *Unilever
- United Soybean Board
- University of Arkansas Division of Agriculture
- University of Wisconsin-Madison College of Agricultural and Life Sciences
- USA Rice Federation
- *Walmart
- World Resources Institute
- World Wildlife Fund – US

*Members marked with an asterisk (*) have joined since the first publiction of this report in July 2012

Field to Market

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decision-making processes for environment, energy, and health policy issues.

For more information about Field to Market, please visit www.fieldtomarket.org.

Abstract

Field to Market, the Keystone Alliance for Sustainable Agriculture, is a collaborative stakeholder group of producers, agribusinesses, food and retail companies, conservation and non-profit organizations, universities, and agency partners that are working together to define, measure, and develop a supply-chain system for agricultural sustainability. This 2012 report presents environmental and socioeconomic indicators for measuring outcomes of on-farm agricultural production in the United States. The report analyzes trends over time at the United States national scale for each of the indicators. Part I analyzes environmental indicators (land use, soil erosion, irrigation water applied, energy use, and greenhouse gas emissions) for six crops (corn, cotton, potato, rice, soybeans, and wheat), demonstrating trends over time from 1980-2011. Results are presented in three formats: resource use/impact per unit of production, resource use/impact per acre, and total resource use/impact. Part II analyzes socioeconomic indicators (debt/asset ratio, returns above variable costs, crop production contribution to national and state gross domestic product, non-fatality injury, fatality, and labor hours) for five crops (corn, cotton, rice, soybeans, and wheat). Each section also highlights additional relevant indicators for consideration given availability of appropriate methodology and datasets. Results demonstrate areas of progress as well opportunities for continued improvement. National scale indicators tracking trends over time in agricultural sustainability outcomes can provide broad perspective, prompt industry-wide dialogue, and identify priorities for more localized investigations and efforts.

Executive Summary

Introduction

Field to Market, The Keystone Alliance for Sustainable Agriculture, is a collaborative stakeholder group of producers, agribusinesses, food and retail companies, conservation and non-profit organizations, universities, and agency partners that are working together to define, measure, and develop a supply-chain system for agricultural sustainability. A proactive approach by a broad-based group will help all in agriculture prepare for the future.

Nearly all estimates of future demand for agricultural goods suggest a need to double agricultural production by 2050, if not before, in order to maintain adequate supplies for a growing world population that will use its expanding income to purchase fiber and fuel products and to diversify diets with more meat, dairy, fruits and vegetables. Field to Market believes this increased production must be accomplished in a manner that does not negatively impact – and actually improves – overall environmental and societal outcomes.

As an initial step, the group 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; and
- Improving the social and economic well-being of agricultural communities

It is within this context that the group is developing metrics to measure the environmental, health, and socioeconomic outcomes of agriculture in the United States at the national, regional, and field scales. These metrics will facilitate quantification and identification of key impact areas and trends over time, foster productive industry-wide dialogue, and promote continued progress along the path toward sustainability.

Objectives and Scope

While global demand, production, and sustainability trends are influenced by a myriad of complex drivers and conditions at a variety of scales, Field to Market's exploration of sustainability metrics focused on United States agriculture and the science-based measurement of outcomes associated with the production of commodity crops. This focus provides important insights for sustainability of U.S. commodities, which represent a significant proportion of the cropland in the United States and are often associated with complex supply chains that require innovative approaches to measurement and data sharing. This current focus provides a starting point for further analysis and for the development of methodologies and approaches that could be further adapted and applied to other contexts.

The objectives of this report are as follows:

1. Analyze trends in progress in environmental and socioeconomic performance for U.S. commodity cropping systems over time.
2. Establish baseline trends against which to monitor future improvements.
3. Create enabling conditions for stakeholders in the United States to contribute to discussion and development of sustainable agriculture metrics and their application toward advancing sustainable practices.
4. Advance an outcomes-based, science-based approach for defining and measuring agricultural sustainability that can be considered and adapted for other geographies and crops.

Criteria for development and inclusion of Field to Market indicators in this report include:

1. National scale – Analyzes national level sustainability performance of crop production. National scale indicators can provide perspective and prompt industry-wide dialogue and context that can be ultimately scaled to more localized investigations and efforts.
2. Trends over time – Metrics that allow comparison of trends over time rather than a static snapshot of farm activity.
3. Science-based – Utilizes best available science and transparent methodologies.
4. Outcomes-based – Provides an inclusive mechanism for considering the impacts and sustainability of diverse agricultural products and practices.
5. Public dataset availability – Utilizes publicly available data. Public, national-level datasets provide a transparent, accessible, and fundamental means to understand sustainability trends.
6. On-farm – Focuses on outcomes resulting from agricultural production within the farm-gate.
7. Grower direct control – Focuses on impacts over which a producer has direct influence through his or her management practices and decisions.

This report provides an update to Field to Market's first report, released in 2009, analyzing environmental indicators for four crops. This 2012 report achieves the following specific advances relative to the 2009 report:[1]

1. Incorporates the most recently available public datasets to extend the environmental trends analyses presented to 2011.
2. Revises the environmental indicator methodologies as appropriate to improve accuracy and reflect best available science.
3. Analyzes two additional crops for environmental indicators (potatoes and rice).
4. Analyzes socioeconomic indicators.

[1] Field to Market. 2009. Environmental Resource Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States, First Report, January 2009. www.fieldtomarket.org

Part I of this 2012 report analyzes national-scale trends for six crops (corn, cotton, potatoes, rice soybeans, and wheat) and five environmental resource indicators (land use, soil erosion, irrigation water applied, energy use, and greenhouse gas emissions); data are analyzed for the United States, 1980 to 2011. Because this 2012 report utilizes updated methodologies, the results presented vary somewhat from those presented in 2009, and are not intended for comparison against the values in the original report. Results in this report are updated for the full time series of 1980 to 2011.

Part II of this 2012 report includes analysis of national-level metrics for socioeconomic indicators for five crops (corn, cotton, rice, soybeans, and wheat). The socioeconomics chapter analyzes trends over time for six indicators (debt/asset ratio, returns above variable costs, crop production contribution to national and state gross domestic product, non-fatality injury, fatality, and labor hours). In addition, the chapter identifies many other potentially relevant socioeconomic indicators for agricultural production that, although they do not fully meet the Field to Market criteria described above, remain important given available data and appropriate consideration of the factors that complicate their analysis.

Environmental Indicators: Results Overview

Over the study period (1980-2011), on average at the national scale in the United States, the following trends were observed. Percent change is relative to single crop and based on the average trend line for the entire study period:

- **Production and Yield**
  - o Total production increased for corn (+101%), cotton (+55%), potatoes (+30%), rice (+53%), and soybeans (+96%); total wheat production decreased (-16%).
  - o Yield per planted acre increased for all crops: corn (+64%), cotton (+43%), potatoes (+58%), rice (+53%), soybeans (+55%), and wheat (+25%).
- **Land Use**
  - o Land use per unit of production (e.g., bushels, cwt and pounds) has improved (decreased) for all six crops because of increased yields: corn (-30%), cotton (-30%), potatoes (-37%), rice (-35%), soybeans (-35%), and wheat (-18%).
  - o Total land use (planted acres) has increased for corn (+21%), cotton (+11%), rice (+9%) and soybeans (+24%) but decreased for potatoes (-15%) and wheat (-33%).
- **Soil Erosion**
  - o Soil erosion per unit of production has improved (decreased) for all six crops: corn (-67%), cotton (-68%), potatoes (-60%), rice (-34%), soybeans (-66%), and wheat (-47%).
  - o Per acre soil erosion has improved (decreased) for corn (-43%), cotton (-50%), potatoes (-34%), soybeans (-41%), and wheat (-34%) and remained constant for rice (rice has historically had low rates of soil erosion). However, improvements in per acre soil erosion for corn, cotton, soybeans, and wheat occurred primarily in the earlier part of the study period; per acre soil erosion has remained relatively constant for these crops in recent years.
  - o Total soil erosion has improved (decreased) for corn (-31%), cotton (-42%), potatoes (-42%), soybeans (-28%), and wheat (-57%) and increased for rice (+9%) (rice has historically had low levels of total soil erosion and increases are likely associated with increased acreage). However, improvements (decreases) in total soil erosion for corn and soybeans occurred primarily in the first half of the study period, with increases occurring in more recent years associated with increased production.

- **Irrigation Water Applied**
  - Irrigation water applied per unit of production has improved (decreased) for all six crops: corn (-53%), cotton (-75%), potatoes (-38%), rice (-53%), soybeans (-42%), and wheat (-12%).
  - Per acre irrigation water applied has improved (decreased) for corn (-28%), cotton (-46%), rice (-25%), and soybeans (-9%) and decreased slightly for potatoes (-2%); per acre irrigation water applied increased for wheat (+6%).
  - Total irrigation water applied decreased for cotton (-35%), rice (-18%), and wheat (-12%) and increased for corn (+27%), potatoes (+31%), and soybeans (+271%).
- **Energy use**
  - Energy use per unit of production has improved (decreased) for all six crops: corn (-44%), cotton (-31%), potatoes (-15%), rice (-38%), soybeans (-48%), and wheat (-12%).
  - Per acre energy use improved (decreased) for corn (-6%), cotton (-2%), rice (-3%), and soybeans (-17%), increased for potatoes (+33%) and wheat (+9%).
  - Total energy use decreased for wheat (-26%), and increased for corn (+14%), cotton (+9%), potatoes (+11%), rice (+6%), and slightly for soybeans (+3%).
- **Greenhouse gas emissions**
  - Greenhouse gas emissions per unit of production have improved (decreased) for all six crops: corn (-36%), cotton (-22%), potatoes (-22%), rice (-38%), soybeans (-49%), and wheat (-2%).
  - Per acre greenhouse gas emissions improved (decreased) for rice (-4%) and soybeans (-18%), and increased for corn (+8%), cotton (+9%), potatoes (+23%), and wheat (+21%).
  - Total greenhouse gas emissions decreased for wheat (-17%), increased slightly for potatoes (+3%) and soybeans (+1%), and increased for corn (+31%), cotton (+20%), and rice (+5%).

In summary, over the study period, all six crops demonstrated progress in their respective national average trends for resource use/impact per unit of production on all five environmental indicators. Improvements in efficiency were driven, at least in part, by improvements in yield for all crops. Due in part to overall increases in production for five of the six crops (excluding wheat) and increases in total land use for four of the six crops (excluding potatoes and wheat), total resource use/impact increased for many crops on many indicators. Per acre resource use/impact was more variable across crops.

These trends – increasing efficiency per unit of production balanced (in some cases) by increasing total resource use or impact – suggest that a challenge for the future will be to continue efficiency improvements such that overall resource limits (e.g., land, water, and energy) are not reached.

Socioeconomic Indicators: Results Overview

- **Debt to asset ratio** (1996-2010)
  - o The debt to asset ratio decreased (improved) (-37%) for general cash grain farms.
- **Returns over variable costs** (1980–2011)
  - o Returns over variable costs for corn, rice, soybeans and wheat decreased during the 1980s, increased in the early to mid-1990s with a slight decrease in the late 1990s and an increase beginning in approximately 2002, providing a w-shaped curve for the time period.
  - o Returns over variable costs for cotton decreased in the early 1980s, maintained flat growth with some variability from the late 1980s to approximately 1998, and then decreased again until the early 2000s when returns stabilized. There has been an increase in returns over variable costs for cotton since approximately 2009.
- **National and state gross domestic product** (1997–2009)
  - o The national growth rate trend has increased (69%) for the agricultural sector contribution to the national GDP.
- **Non-fatality injury** (1995–2010)
  - o The number of work related injuries decreased (-55%) for all crop-producing farms with eleven or more employees.
  - o The number of lost work days (-76%) and the incidence of one or more work days lost (-49%) due to injury both decreased for crop farms (excluding fruit, vegetable, and other specialty crops).
- **Fatality** (1993–2010)
  - o Fatalities decreased (-32%) for crop farms (excluding fruit, vegetable, and horticulture farms).
- **Labor hours** (1990–2011)
  - o The implied time to produce corn (-59%, -75%), cotton (-69%, -75%), rice (-43%, -58%), and soybeans (-66%, -74%) decreased both per acre and per unit of production, respectively.
  - o The implied time to produce wheat decreased (-12%) per bushel but remained relatively flat (-1%) per planted acre.

In summary, the indicators for debt to asset ratio, fatalities, and non-fatality injury decreased (improved) over their respective time periods and farm classification. Returns over variable costs have been inconsistent over the indicator's respective time period, but have been increasing for all crops, excluding cotton, since approximately 2002, and for cotton since 2009. Labor hours have decreased for all crops excluding wheat. Overall, the agricultural sector's contribution to national GDP has increased over the explored time period.

Conclusions and Next Steps

This report does not define a benchmark level of sustainability for agriculture. Rather, it explores broad-scale, commodity-level progress relevant to key challenges and indicators for agricultural sustainability and provides methods by which to measure and track trends over time. The results presented in this report demonstrate important advancements on a variety of environmental, social, and economic indicators as well as continued opportunities and challenges. For example, gains in productivity and per unit of production resource use efficiency are important in meeting the challenges of increasing demand and limited resources, yet increases in total levels of resource use in order to meet these demands underscores the importance of continued improvements given absolute resource limits. Similarly, sustaining and accelerating improvements demonstrated in this report for many social and economic dimensions of agriculture will be fundamental to sustainable production, and will also be influenced by evolving patterns in demand, urbanization, demographics, and supply chain expectations.

The trends presented here can help inform the sustainability conversation, enhance our understanding of progress, challenges, and opportunities and provide a broad-scale baseline against which to monitor future change. This broad-scale understanding and context enables stakeholders to have better-informed discussions of the priorities and opportunities for improvement at the field and farm level. Field to Market recognizes that while the analyses contained in this report are important and necessary to understanding sustainability, they alone are not sufficient for fully comprehending and ultimately addressing sustainability challenges. Accordingly, Field to Market's work on outcomes-based indicators for agricultural sustainability continues, with the following specific and significant considerations for future analyses.

Expansion of indicators. The indicators presented in this report do not represent the full suite of sustainability indicators for agriculture. Expansion of the current indicator set to include additional crops as well as additional environmental and socioeconomic indicators may occur given available methods and datasets. In particular, Field to Market continues to explore development of metrics for water quality and biodiversity.

Refinement of methods and data. Methodologies and datasets for the current national/regional/state level indicators provided here may be updated as appropriate to reflect best available science as well as the release of public data. Capacity to continue and enhance these kinds of analyses is dependent on the availability of the public data sources upon which it relies. Public, national level datasets provide a transparent, accessible, and fundamental means to understand sustainability trends.

Scaling of approaches. Downscaled analyses may require more sophisticated methodologies and datasets to allow for higher resolution, better interpretation of trends at local levels, and better understanding of how specific decisions affect specific resources and geographies. This report utilizes methods that strive for high scientific sophistication while also recognizing the limits of working with public data and at a broad-scale. More locally-scaled analyses may utilize and even require methods not feasible and data not available at the national scale, as local decisions will require more specific information to inform management and decision-making.

Exploration of impacts. Further analyses at all scales are needed to better understand the total impacts of crop production. For example, within our environmental indicators, efficiency and total use trends at the national scale do not capture the specific challenges associated with resource limitations and impact, including those at smaller scales. While many national trends show improvement for particular crops, whether for efficiency measures or total resource, overall national or even global resource limitations cannot be overlooked, nor can specific local examples of continued challenges. For example, sustainability can be impacted by nationally and globally available cropland and energy sources, as well as by groundwater availability for a particular regional or local aquifer. Conversely, some national trends may show overall increases in total uses for a particular crop even while success stories may be occurring at more local levels or may be occurring in consideration of all crops grown in a particular area.

Aggregation of results across all crops. Further analyses are needed to better understand the cumulative or aggregate impacts of all crop production. While crop-by-crop analyses provide important information for commodity sectors and supply chains, aggregation of data for all crops may provide further insight into directional changes in total uses. For example, increases or decreases in resource use for a single crop may actually be offset by decreases or increases for another crop, and aggregate results may in some cases be directionally different than by-crop results, both at the national and local scale. Aggregate total resource uses may also vary in direction at the local scale as compared to national scale; for example, due to land use change either away from agricultural production (e.g., conversion to urban land) or into production (e.g., release of Conservation Reserve Program land back into production). Similarly, for socioeconomic indicators, further analyses at additional scales and for the aggregate of agricultural production are needed, as are enhanced measures of impact on the farmer and farm community.

Evaluation of context and drivers. Further analyses are also needed to better understand both the context and drivers underlying the trends reported here. Context and drivers can include conditions both internal and external to agricultural systems – such as resource limitations and conditions, at a variety of scales, individual farmer choices, availability of new science and technology, supply chain and economic conditions, price signals, consumer behaviors, demographic changes, policy and governance changes. Because agriculture is an incredibly complex system and analysis of context and drivers equally complex, Field to Market does not attempt in this report to analyze nor speculate on them unless they are explicitly evident in the datasets used to build the metrics themselves.

Examination of recent trends versus historical trends. Further analyses are also particularly needed to better understand the most recent trends, drivers, and contexts for sustainability. This report highlights results in summary form – for example, percent change over the full 30-year study period – and also includes data demonstrating the full time series of trend lines for each crop and indicator. There are many more stories to be further explored and explained within the data provided in this report, including, and especially, those for which more recent trends may represent accelerations, decelerations, or reversals of the overarching 30-year trend-lines. The longer time period provides important historical context and the most recent trends may signal important considerations for the future.

Expansion to additional crops and geographies. Field to Market's primary focus is currently on commodity agricultural production in the United States. However, the Alliance seeks to inform efforts focused on other crops and geographies by facilitating information-sharing, coordination and collaboration regarding methodologies and approaches. As an example, Field to Market's 2009 report was recently adapted for Canadian field crops to explore trends over time for eight different Canadian crops including wheat, oat, lentil, canola, peas and flax.[2] Field to Market continues exploration of opportunities to leverage and adapt the current work to new contexts, both within and beyond the United States.

Connecting trends to individual grower education and action. Field to Market's analysis of broad-scale trends provides a mechanism to measure overall progress. Yet what moves the "needle" of sustainability outcomes at the broad scale are individual practices and outcomes at the field and farm scale. Complementing its efforts to analyze broad-scale trends, Field to Market has also developed the Fieldprint Calculator, a free, online educational and awareness tool that allows individual growers to analyze the outcomes of their own management practices at the field level and compare them to broader-scale benchmarks as well as to trends within their own peer or pilot groups (www.fieldtomarket.org). Field to Market is actively engaged in piloting these tools and methodologies with farmers to identify future improvements and understand the utility of these tools in informing management actions and driving continuous improvements.

The above-recommended future investigations represent significant opportunities for which this report is intended as a starting place. Through this report and Field to Market's advancement of agricultural sustainability metrics and tools that quantify the impacts of cropping practices 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 hope and intent is that such approaches will ultimately inform mechanisms to promote continuous improvements at the field level that aggregate, 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.

[2] Serecon Management, for Pulse Canada, Canadian Canola Growers Association, Canadian Wheat Board, Ducks Unlimited, Flax Council of Canada, and General Mills. 2011. Application of Sustainable Agriculture Metrics to Selected Western Canadian Field Crops: Final Report. Edmonton, Alberta. http://www.pulsecanada.com/fieldtomarket

List of Figures and Tables

Part I: Environmental Indicators Report

1. Introduction

Field to Market, The Keystone Alliance for Sustainable Agriculture, is a collaborative stakeholder group of producers, agribusinesses, food and retail companies, conservation and non-profit organizations, universities, and agency partners that are working together to define, measure, and develop a supply-chain system for agricultural sustainability. A proactive approach by a broad-based group will help all in agriculture prepare for the future.

Nearly all estimates of future demand for agricultural goods suggest a need to double agricultural production by 2050, if not before, in order to maintain adequate supplies for a growing world population that will use its expanding income to purchase fiber and fuel products and to diversify diets with more meat, dairy, fruits and vegetables.[3] Field to Market believes this increased production must be accomplished in a manner that does not negatively impact – and actually improves – overall environmental and societal outcomes.

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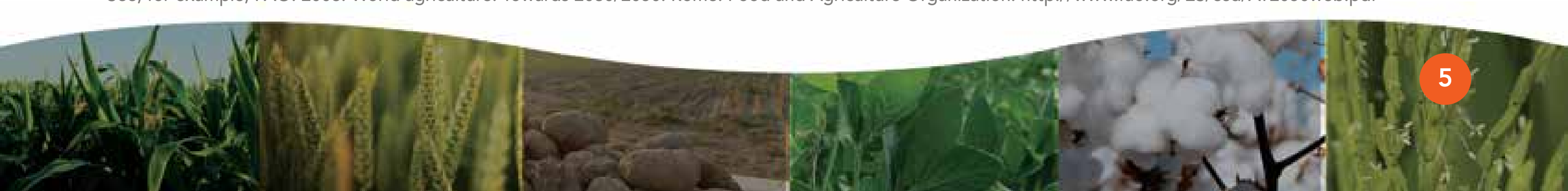
- Increasing agricultural productivity to meet future nutritional needs
- Improving the environment, including water, soil, and habitat
- Improving human health through access to safe, nutritious food; and
- Improving the social and economic well-being of agricultural communities

It is within this context that the group is developing metrics to measure the environmental, health, and socioeconomic outcomes of agriculture in the United States at the national, regional, and field scales. These metrics will facilitate quantification and identification of key impact areas and trends over time, foster productive industry-wide dialogue, and promote continued progress along the path toward sustainability.

While global demand, production, and sustainability trends are influenced by a myriad of complex drivers and conditions at a variety of scales, Field to Market's exploration of sustainability metrics has focused on United States agriculture and the science-based measurement of outcomes associated with the production of commodity crops. This focus provides important insights for sustainability of U.S. commodities, which represent a significant proportion of the cropland in the United States and are often associated with complex supply chains that require innovative approaches to measurement and data sharing. This current focus provides a starting point for further analysis and for the development of methodologies and approaches that could be further adapted and applied to other contexts.

[3] See, for example, FAO. 2006. World agriculture: Towards 2030/2050. Rome: Food and Agriculture Organization. http://www.fao.org/ES/esd/AT2050web.pdf



In January 2009, Field to Market released a report on national-scale trends in environmental resource indicators for corn, cotton, soybean, and wheat production in the United States.[4] Using publicly-available data, national-scale metrics were developed to measure outcomes for five environmental indicators: land use, soil erosion, irrigation water applied, energy use, and climate impact (greenhouse gas emissions). The metrics were applied to quantify environmental outcomes for four commodity crops –corn, cotton, soybeans, and wheat—produced through agricultural practices in the United States. The report quantified trends over time for these crops and indicators from 1987-2007.

The objectives of both the 2009 and 2012 environmental indicator reports are:

1. **Analyze trends** in progress in environmental and socioeconomic performance for U.S. commodity cropping systems over time.
2. **Establish baseline** trends against which to monitor future improvements.
3. **Create enabling conditions** for stakeholders in the United States to contribute to discussion and development of sustainable agriculture metrics and their application toward advancing sustainable practices.
4. **Advance an outcomes-based, science-based approach** for defining and measuring agricultural sustainability that can be considered and adapted for other geographies and crops.

This 2012 report seeks to further address and advance the objectives described above and also achieve the following specific advances relative to the 2009 report:

1. Incorporate the most recently available public datasets to extend the environmental trends analyses.[5]
2. Revise the environmental indicator methodologies as appropriate to improve accuracy and reflect best available science.
3. Analyze additional crops – rice and potatoes.
4. Analyze socioeconomic indicators (Part II of this report).

Part I of this 2012 report updates the 2009 environmental indicators approaches to include the most recent publicly available data, revises and updates the methodology for the five original resource indicators listed above, and analyzes potatoes and rice in addition to the four crops included in the 2009 report. Since 2009, Field to Market has also actively been working to evaluate indicators for water quality and biodiversity at the national and field/farm scales. A brief overview of this work is provided in this report.

Because this 2012 report utilizes updated methodologies, the results presented vary somewhat from those presented in 2009, and are not intended for comparison against the values in the original report. Results in this report are updated for the full time series of 1980 to 2011.

[4] Field to Market. 2009. Environmental Resource Indicators for Measuring Outcomes of On-Farm Agricultural Production in the United States, First Report, January 2009. www.fieldtomarket.org

[5] Examples of new datasets include: productivity estimates through 2010 from NASS, 2007 Agricultural Census and 2008 Farm and Ranch Irrigation Survey, 2002 and 2007 soil erosion data from NRI, new ARMs Survey data, and updated fertilizer use data by crop

2. Data and Methods

2.1. Data and Methods Overview

Consistent with the 2009 Field to Market report, criteria for development and inclusion of Field to Market indicators in the 2012 report are as follows:

1. National scale – Analyzes national level sustainability performance of crop production. National scale indicators can provide perspective and prompt industry-wide dialogue and context that can be ultimately scaled to more localized investigations and efforts.
2. Trends over time – Metrics that allow comparison of trends over time rather than a static snapshot of farm activity.
3. Science-based – Utilizes best available science and transparent methodologies.
4. Outcomes-based – Provides an inclusive mechanism for considering the impacts and sustainability of diverse agricultural products and practices.
5. Public dataset availability – Utilizes publicly available data. Public, national-level datasets provide a transparent, accessible, and fundamental means to understand sustainability trends.
6. On-farm – Focuses on outcomes resulting from agricultural production within the farm-gate.
7. Grower direct control – Focuses on impacts over which a producer has direct influence through his or her management practices and decisions.

For this study, data has been retrieved and assembled across six primary crops in the United States:

Crop	Yield Unit	Description
Corn	bu.	Bushel, 56lbs. of corn grain per bushel
Cotton	lb. of lint	Pounds (lbs.) of lint
Potatoes	cwt	Hundred weight, (100 lbs.)
Rice	cwt	Hundred weight, (100 lbs.)
Soybeans	bu.	Bushel, 60 lbs. of soybean seed per bushel
Wheat	bu.	Bushel, 60 lbs. of wheat grain per bushel

Together, the production of these six crops has comprised approximately 73 percent of the acres of agricultural cropland use in the United States for the past several decades. In 2011, these crops comprised 73.9 percent of the 293.4 million acres of U.S. agricultural crops harvested and had combined crop value of $119 billion; they accounted for roughly 58% of U.S. crop cash receipts during the period 2007 through 2011.[6] It is our intention that the methods used could be applied to a full range of technology choices and to other crops produced in the United States or elsewhere assuming sufficient data and, perhaps, with some modification.

This report focuses on five important environmental indicators for agricultural sustainability:

1. Land use
2. Soil erosion
3. Irrigation water applied
4. Energy use
5. Greenhouse gas emissions

In selecting environmental indicators, Field to Market strove to identify a discrete and relatively small set of key outcome indicators critical for agricultural sustainability. The five indicators listed above, along with water quality, total water use, and biodiversity, were prioritized by the multi-stakeholder membership of Field to Market.

[6] USDA Economic Research Service (ERS). 2012. Farm Income and Costs: 2012 Farm Sector Income Forecast. http://www.ers.usda.gov/Briefing/FarmIncome/nationalestimates.htm

Water quality, total water use, and biodiversity are recognized by Field to Market as important environmental indicators of agricultural sustainability, and continued discussion of appropriate metrics for these areas continues within the Alliance. A brief discussion of these indicators is included in the Methods section below.

Consistent with the outcomes approach taken by this group, the impacts of product inputs such as pesticide and fertilizer use are accounted for in outcomes indicators such as energy use, greenhouse gas emissions, biodiversity, and water quality. The methodology for incorporating these inputs into the current energy and greenhouse gas emissions indicators is explained below.

Results for each indicator are presented in three formats – all are valuable and additional discussion of the relative values and caveats for each is provided later in the report:

1. **"Efficiency"[7] indicators** showing resource indicator (use or impact) per unit of production. "Efficiency" measures show change in use or impact over time relative to our ability to meet productivity demands and normalizes the metrics to a common unit of comparison for producers and stakeholders.
2. **Per acre resource use or impact.** Per acre resource use similarly normalizes the metrics to a common unit of comparison, however it should be noted that an equal amount of resources may be used per acre with varying production levels achieved.
3. **Total use indicators** showing the annual use or impact per acre multiplied by total acres harvested. Total resource use or impact indicators are essential for informing conversations regarding total resource restraints or limits.

Results are expressed graphically in three forms:

1. **A summary table of percent change** over the full study period (based on a least squares trend analyses from 1980-2011) for each crop, indicator, and unit of analysis, found in the summary of results for each crop.
2. **A summary spidergram for "efficiency" indicators over time,** found in the summary of results for each crop. The spidergram visually demonstrates the change in the overall efficiency footprint or "Fieldprint" over time. In order to facilitate comparison and evaluate relative changes over time across multiple indicators with differing units of measure (e.g., BTU for energy vs. CO_2e for greenhouse gas emissions in carbon dioxide equivalents), each efficiency indicator is indexed where actual values observed in the year 2000 are set equal to 1. Therefore, a 0.1 unit change in the index value of an individual indicator is equal to a 10% percent change relative to the actual value in the year 2000. Trends that demonstrate movement toward the center of the spidergram (toward a value of zero, or a shrinking of the "Fieldprint") represent an improvement of efficiency, or resource use/impact per unit of production, over time. Other prominent sustainability metrics, both pertaining to agriculture and apart from agriculture, have relied on normalized metrics including measures such as per capita, per unit of production, or per unit of value of production. In the widely acknowledged *2005 Environmental Sustainability Index*,[8] the authors suggest "…sustainability is a characteristic of dynamic systems that maintain themselves over time; it is not a fixed endpoint that can be defined;" under this interpretation, normalization becomes optimal in that it allows us to compare trends over time.

[7] Efficiency is typically defined and expressed as output/input. For our purposes, to emphasize the importance of considering the resources needed to produce a unit of crop, we produce inverse efficiency measures that are normalized to a unit of production, thus expressing input/unit of output, e.g., energy use per bushel of corn produced.

[8] Esty, D.C., M. Levy, T. Srebotnjak, and A. de Sherbinin. 2005. 2005 Environmental Sustainability Index: Benchmarking National Environmental Stewardship. New Haven: Yale Center for Environmental Law & Policy. http://www.yale.edu/esi/ESI2005_Main_Report.pdf

3. Individual line graphs for each crop, indicator, and unit of analysis (production, acre, and total) are also found in each crop summary section. The graphs chart actual resource values (e.g., actual BTU per bushel) by year for the entire study period (1980-2011). The regression equations and R2 values for each line graph are provided. The line graphs provide additional resolution regarding changes over time and the conformity of those changes with average trend line for the full study period.

Data and methods have been standardized as closely as possible across all crops. The data used in this report have been retrieved from numerous sources – all are within the public domain. 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 due to the fact that most data underlying the indicators were expressed on a per acre basis; however, there were some exceptions, for example, where data were based on total production, weighting was conducted based on production. Data and methods for each environmental resource indicator are further explained below. Data analysis and summary have been completed by IHS/Global Insight, an economic, financial analysis, forecasting and consulting firm with more than 40 years of experience.

This report utilizes methods that strive for a high degree of scientific sophistication while also recognizing the limits of working with public data and at a broad-scale. More locally-scaled analyses may utilize and even require methods not feasible and data not available at the national scale; examples include more complex models of nitrous oxide emissions (N_2O) or soil erosion that are available at the field scale but were not within the scope of this study to execute and/or aggregate at the national scale. In these cases, a simpler approach is justified by the national-scale nature of the trends analyses conducted here. Methodologies and datasets for the current indicators provided here may be updated as appropriate to reflect best available science as well as the release of public data.

A draft report was shared with 9 peer reviewers (see Acknowledgments) and feedback was incorporated wherever possible to correct, clarify, or better frame the methodology and the scope of the report.

2.2. Overview of Updated Methods for the 2012 Report

Field to Market has updated its methodologies for this report in several areas, to reflect best available science and learnings that have occurred since the 2009 report. Most notably, the updates include:

- **Threshold for inclusion of a practice or input:** As a guiding principle, to be included in the calculation of the metric, a particular production practice or input must contribute at least 1% of the resource use or impact for the indicator in question to be included as a separate factor. For example, if a practice contributes less than 1% of total BTU to an energy footprint, and is not already captured by an included activity, it is not included. In the prior (2009) report, no such threshold was set; this threshold allows for better consistency across all crops and indicators, ensures inclusion of practices that influence the calculation of a particular metric, and also sets a standard for allowing practices with relatively negligible impact on the calculation to be omitted. This approach is considered appropriate given the scope and intent of the analyses in developing national-scale averages. However, it should be noted that there are some exceptions under which practices representing less than 1% of the metric are included; these include circumstances in which available data capture a suite of practices, some of which may fall below the 1% threshold, as well as specific examples for which a practice may represent less than 1% of the footprint at a national-average level but has more significant impact at a more local level and was deemed important to incorporate. An example of the latter exception is the harvest of crop residue; the harvesting of wheat straw can have significant impact both economically and for greenhouse gas emissions at a regional level, however, at the national scale it represents less than 1% of total emissions for wheat. Should the practice become more prevalent on a national scale, its influence on national average greenhouse gas emissions for wheat would similarly increase.

- **Defined end-point for measurement:** Field to Market's 2012 report now clearly defines the end-point for calculation of the environmental footprint as the point of sale of the crop. By specifying the point-of-sale as the end point for measurement, this approach is consistent with the criterion that metrics represent practices and actions within a grower's control. The point of sale can vary by farmer and by crop; for example, some growers may deliver their crop to a grain elevator or mill while others sell their crop at the farm bin or point of storage. In the example of the grain being sold at the farm, the impact of transporting the crop to the mill would not be part of the farmer's crop field-print.

- **Planted versus harvested acres:** The 2009 Field to Market report considered only harvested acres. The rationale was that harvested acres are most often used in data reporting and are most familiar to agriculture producers. However, the use of planted acres accounts for abandonment due to weather or other adversity that causes the crop not to be harvested and therefore is a more comprehensive measure. At the national scale, inclusion of abandonment is an important means of understanding the impacts of losses on the overall efficiency of input usage and the relationship between impacts and productivity. In this 2012 report, we now analyze data and present results in terms of planted acres. The use of intentional land fallowing or double cropping are not explicitly captured in the 2012 report nor were they captured in the 2009 version. Attempts to better attribute land resources to these practices may be made in future updates.
- **Co-products and by-products:** The 2012 methodologies now account for economic allocation of co-production of cotton seed and wheat straw. 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%. The 83% 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%

The economic importance of wheat straw as a co-product of wheat varies in the U.S. by region and year. Cotton seed is an economically important co-product of cotton and is a consistent component of income for all U.S. cotton producers. Values representing wheat 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.

- **Metric-specific changes:**

o With the exception of an adjustment to account in this report for planted acres rather than harvested acres, the land use and irrigation water applied methodologies remain the same as those reported in 2009.

o The 2012 soil erosion methodology no longer compares soil erosion above tolerable (T) level. Now the metric includes total soil erosion, allowing for reporting of trends in reduction below T and recognizing that T is a highly location-specific concept.

o For energy and greenhouse gas calculations, additional practices and contributors are considered; for example, the methods now account for embedded energy and emissions from seed and drying, and include updated N_2O factors. Soil carbon is no longer counted as an offset for greenhouse gas emissions.

2.3. Land Use Indicator

Land is a primary requirement to produce agricultural goods. By its very nature, agriculture domesticates the land under production. A 2001 USDA Economic Research Service Report stated, "Land quite literally underlies all economic activity, but nowhere more than for agriculture. Land is the primary input for crop production and grazing livestock, a source of rural amenities, and a store of value for farmland owners."[9] According to 2007 land use data from the USDA, the United States composes 2.3 billion acres in total; 17.7% of these are cropland, or 406 million acres (this represents a decrease in total cropland from that reported by 2002 USDA land used data, which reported 19.5% of these acres are cropland, or 442 million acres).[10] [11]

Other land uses include pasture, forest, special uses and other.[12] These categories can be divided further into more specific uses such as grassland, urban, rural parks and wildlife, cropland used for pasture, and cropland idled to name a few.[13] [14] Each type of land use contributes its own challenges and opportunities for sustainability, especially agriculture as a result of its high level of productivity per acre and large land use percentage.[15] [16]

The focus of this report is on changes over the study period (1980-2011) in U.S. cropland use, which will be referred to as agriculture for corn, cotton, potatoes, rice, soybeans and wheat. We do not attempt to analyze or compare current agriculture against a pre-industrial baseline. Field to Market recognizes that land use decisions by U.S. agricultural producers are guided by many factors, including international price signals, Farm Bill policies and programs, and biofuel policies. The complex interaction of many drivers can influence whether a farmer plants one crop over another or chooses to enroll in or exit a conservation program that provide incentive to idle land, e.g., the Conservation Reserve Program or Wetlands Reserve Program.[17] There is evidence of recent declines in CRP enrollment (since 2007), with implications for total land use as well as for other sustainability indicators influenced by increases in planted area.[18]

[9] USDA. 2001 Sep 13. Urban Development, Land Use and Agriculture. Washington, D.C.: United States Department of Agriculture.

[10] Lubowski RN, Vesterby, M, Bucholtz, S, Baez, A, and MJ Roberts. 2006. Major Uses of Land in the United States, 2002. United States Department of Agriculture, Economic Research Service; Report nr EIB-14.

[11] 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.

[12] USDA. 2007, Dec 21. Major Land Uses. Washington, D.C.: United States Department of Agriculture. http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp

[13] Lubowski RN, Vesterby, M, Bucholtz, S, Baez, A, and MJ Roberts. 2006. Major Uses of Land in the United States, 2002. United States Department of Agriculture, Economic Research Service; Report nr EIB-14.

[14] USDA. 2007, Dec 21. Major Land Uses. Washington, D.C.: United States Department of Agriculture.

[15] Prince, SD, Haskett, J, Steininger, M, Strand, H, and R Wright. 2001. Net Primary Production of U.S. Midwest Croplands from Agricultural Harvest Yield Data. Ecological Applications 11:1194-1205.

[16] Turner II, B L, Lambin, EF, and A Reenberg. 2007. Land Change Science Special Feature: The Emergence of Land Change Science for Global Environmental Change and sustainability. PNAS 104

[17] U.S. Farm Bill Conservation Titles. http://www.nationalaglawcenter.org/assets/farmbills/conservation.html#environmental; Agriculture: A Glossary of Terms, Programs, and Laws, 2005 Edition. http://ncseonline.org/nle/crsreports/05jun/97-905.pdf; Sodsaver: Protecting Prairie and Producers. http://www.iwla.org/index.php?ht=d/ContentDetails/i/1359/pid/223; Conservation Title Food, Conservation and Energy Act of 2008. http://www.nacdnet.org/policy/agriculture/farmbill/2007/NACD%20Farm%20Bill%20Conservation%20Title%20Summary.pdf

[18] Conservation Reserve Program. USDA FSA. 2010. http://www.apfo.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp-st;

There is also evidence that agricultural land is being converted to suburban and urban areas.[19 20] Field to Market recognizes that these and other trends are important drivers underlying changes in amount and patterns of land use for particular crops, and that they influence production choices and sustainability outcomes on working lands. However, consistent with the overall scope and approach of this report, here we focus on reporting changes in cropland use for the production rather than providing an analysis of the drivers.

Data used in this analysis are on a planted basis; the use of planted acres accounts for abandonment due to weather or other adversity that causes the crop not to be harvested. At the national scale, inclusion of abandonment is an important means of understanding the impacts of losses on the overall efficiency of input usage and the relationship between impacts and productivity.

Yield data are derived from U.S. Department of Agriculture's Annual Crop Production report.[21] Data for measuring land use have come from the National Agricultural Statistics Service (NASS), a division of the United States Department of Agriculture (USDA). The data were drawn from the final estimates provided in the Annual Crop Production report released in January 2012.[22] USDA's survey estimates of yield and farmed land area are considered the best measure available for U.S. agriculture, as well as much of the agriculture around the world.[23]

- *Total Land Use = Planted Acres*
- *Yield = Unit of Production per Planted Acre*
- Land Use "Efficiency" Indicator = Planted Area per Unit of Production

The land use "efficiency" indicator is thus a simple inverse of yield, yet provides a unique perspective that emphasizes and normalizes resource use against a unit of production; as with other "efficiency" indicators presented throughout this report, normalization against a unit of production provides a new mechanism of comparison and a complement to the total use and yield measures.

Results are presented as total resource use (acres), yield (production per acre), and inverse-efficiency (acre per unit of production). Average trends for the entire study period are calculated using a least squares trends analysis. Efficiency data are indexed where the year 2000 equals 1 and displayed with other resource indicators on a summary spidergram by crop.

19 Hart, JF. 2001. Half a Century of Cropland Change. Geographical Review 91:525-543.

20 Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Washington D.C.: Island Press. http://www.millenniumassessment.org/documents/document.356.aspx.pdf

21 USDA NASS. 2008. Crop Values 2007 Summary. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. http://www.usda.gov/nass/PUBS/TODAYRPT/cpvl0208.pdf

22 U.S. Department of Agriculture National Agriculture National Agriculture Statistics Service. 2012. Crop Production 2011 Summary. Washington, D.C.: United States Department of Agriculture, National Agrigcultural Statistics Service. http://usda01.library.cornell.edu/usda/current/CropProdSu/CropProdSu-01-12-2012.pdf

23 Yilmaz, MT, Hunt, ER Jr, and TJ Jackson. 2008. Remote sensing of vegetation water content from equivalent water thickness using satellite imagery. Remote Sensing of Environment 112:2514-2522.

2.4. Soil Erosion Indicator

Soil is fundamental to efficient and economical food production. While renewable over the long-run, excessive soil erosion can have significant adverse effects on agricultural productivity and environmental health. Beyond the loss of productivity, movement of soil from the field has negative implications on surface water quality and the ecosystems involved.

Soil erosion processes are predominantly caused by wind and water, and have been occurring on the land as long as there has been soil. Tillage practices that result in soil exposed to these elements without vegetative cover greatly accelerate the rates of soil erosion. Agricultural practices in the early part of the 20th Century coincided with a regional drought to produce the collapse of agro-ecosystems across the Great Plains, commonly referred to as the Dust Bowl. Great storms of soil were transported by wind across Texas, Oklahoma, and Kansas (and observed as far east as Ohio), and became a symbol of the need for conservation practices in agricultural production.

While many models exist to predict soil erosion due to wind and water erosion, this report utilizes soil erosion data as measured in a government report called the National Resource Inventory (NRI) from the Natural Resources Conservation Service (NRCS); the most recent data from the NRI is for 2007.[24] This section provides an overview of the NRI data, how they were developed by NRCS, and how they are utilized by Field to Market. Field to Market did not collect or model soil erosion for this report; all sampling and modeling procedures (and associated assumptions and parameters) were established by NRCS and reported in NRI (please refer to references for additional information about the NRI methodology and data).

The NRI survey program is scientifically based, employing recognized statistical sampling methods. The 2007 NRI was conducted by NRCS in cooperation with Iowa State University's Center for Survey Statistics and Methodology (ISU-CSSM), which serves as the NRI Statistical Unit providing statistical and survey methods support to the NRI survey program.

The NRI provides the following overview of its sampling methodology:[25]

> "The universe of interest for the NRI survey consists of all surface area (land and water) of the United States. The sample covers all land ownership categories including Federal, although NRI data collection activities have historically concentrated on non-Federal lands. The NRI sample was selected on a county-by-county basis, using a stratified, two-stage, area sampling scheme. The two stage sampling units are (1) nominally square segments of land, and (2) points within the segments. The segments are typically half-mile-square parcels of land equivalent to 160-acre quarter-sections in the Public Land Survey System, but there are many exceptions in the western and northeastern United States. Three specific sample point locations were selected for most selected segments, although two were selected for 40- acre segments in irrigated portions of some western States, and some segments originally contained only one sample point."

From 1982 to 1997 these NRI data were collected on five-year cycles, but beginning in 2000 they were collected annually. The data were collected for 800,000 sample sites from 1982-1997, but in 2000 forward the data were collected from about 200,000 sample sites.

[24] U.S. Department of Agriculture Natural Resources Conservation Service. 2010. 2007 National Resources Inventory, Soil Erosion on Cropland. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_012269.pdf

[25] U.S. Department of Agriculture. 2009. Summary Report: 2007 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. 123 pages. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS//stelprdb1041379.pdf

Processing these data required aggregation at many levels for comparison. The NRI describes the computation of erosion data using models for water (the Universal Soil Loss Equation or USLE) and wind (the Wind Erosion Equation) (please see the NRI summary document for additional information, including the conservation practices evaluated using USLE):[26]

> "NRI erosion estimates are based upon erosion prediction models rather than on-site measuring of soil detachment, transport, and deposition. The erosion prediction models provide estimated average annual (or expected) rates based upon the cropping practices, management practices, and inherent resource conditions that occur at each NRI sample site. Climatic factors used in the erosion prediction equations (models) are based upon long-term average conditions and not upon one year's actual events. NRI estimates of sheet and rill erosion utilize standard Universal Soil Loss Equation (USLE) technology rather than revised USLE (RUSLE) methodology so that it is possible to make comparisons back to the year 1982. Erosion estimates are currently made only for cropland, CRP land, and pastureland. Erosion prediction models for rangeland are currently under development and evaluation."

The NRI database contains both computed (estimated) soil loss and the individual factors, for both the USLE and WEQ, for all points that are Cropland, Pastureland, or CRP land in a given year. Erosion data are not given for points that are any other land cover/use. If a sample point changes land cover/use between two points in time, it has erosion equation factors for the years it is Cropland, Pastureland, or CRP land – but not for any years that is some other land cover/use. This is an important factor to keep in mind when trying to estimate erosion rates for a particular area – to only account for those sample points with a land cover/use of Cropland, Pastureland, or CRP land. It is incorrect to average USLE rates over the land area of an entire State, rather than just some portion of the agricultural land.

NRCS summed data for wind and water (sheet and rill) erosion to estimate total erosion from cultivated cropland by state for the reference years 1982, 1987, 1992, 1997, 2002, and 2007. Working with the statisticians at NRCS and the NRI databases, area-weighted estimates were developed using data on a crop planted area on a county basis to quantify the soil erosion by crop, by state, for the comparison years.

[26] Ibid.

Results are presented as total resource impact (tons), resource impact per acre (soil erosion per planted acre) and inverse-efficiency (soil erosion per unit of production). Efficiency data are indexed where the year 2000 equals 1 and displayed with other resource indicators on a summary spidergram by crop.

In the 2009 report, Field to Market presented results relative to the T value (soil loss tolerance value) as defined by NRCS and the NRI; T is the average annual erosion rate (tons/acre/year) that can occur and still permit a high level of crop productivity to be sustained economically and indefinitely. Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre. In the earlier Field to Market report, T was subtracted from the average soil erosion rate and the difference was reported; in the event that soil erosion was less than T, it was assigned a zero value. However, in this 2012 report, Field to Market is presenting the absolute rather than net soil erosion rates. This change was made in recognition of the site-specific nature of T, debate regarding the merit of T as a management tool, and in order to recognize soil erosion rates below T. A reviewer of the current report noted that more complicated physical metrics could provide a better indicator against which to assess the importance of existing erosion rates, and an economic rationale could be used by comparing the erosion rate and crop yield; given the scope of this exercise, additional comparative analyses have not been conducted but could be the subject of other studies.

In general, while more sophisticated approaches for estimating soil erosion may be utilized at smaller scales and with private data to better predict and measure site-specific soil erosion, disaggregate water and wind erosion reporting, and otherwise improve reporting and analysis for soil erosion at the field level, the use of the NRI data is appropriate given the scope of this report in analyzing trends at the national scale and utilizing publicly available, national-scale datasets. Field to Market explored the possibility of updating its national-scale methodology for soil erosion by moving from the use of USLE to RUSLE2; however, the NRI currently evaluates soil erosion trends at this scale only using USLE. As a measure of relative change over time, USLE remains appropriate, however, RUSLE2 provides more accuracy in terms of absolute numbers and Field to Market will utilize it for its national scale reporting if and when NRI makes this transition (Field to Market currently uses RUSLE2 in its Fieldprint Calculator field-scale methodology).

Results are presented as total resource loss (total tons of soil erosion), average soil erosion per acre, and soil erosion per unit of production. Average trends for the entire study period are calculated using a least squares trends analysis. Efficiency data are indexed where the year 2000 equals 1 and displayed with other resource indicators on a summary spidergram by crop.

2.5. Irrigation Water Applied Indicator

Water is becoming an increasingly scarce resource[27] due to greater demands associated with population growth, urbanization and accessibility.[28 29] Increased population means increased food requirements.[30] These increased demands on water create more competition for this finite resource.

Water is an important limiting factor for crop production.[31] Without an adequate and timely water supply, crop production is not possible.[32 33] The 2008 Farm and Ranch Irrigation survey reported 18 percent of harvested cropland in the U.S. is irrigated.[34] In 2005, irrigation water withdrawals in the U.S. accounted for 31 percent of total withdrawals.[35]

This report presents a method for calculating total irrigation water applied, average irrigation water applied per acre, and average irrigation water applied per incremental unit of production achieved due to irrigation. We focus on irrigation water applied as a primary resource over which growers have direct control. Irrigation water applied does not necessarily equal irrigation water use in all contexts, as use is dependent on plant processes that either utilize the water for growth or result in the return of water to the watershed. This report recognizes this distinction and does not attempt to analyze the actual use of irrigation water by plants nor the rate of return of water applied back to the watershed or aquifer.

[27] Gonzalez-Alvarez, Y, AG Keeler, and JD Mullen. 2006. Farm-level irrigation and the marginal cost of water use: Evidence from Georgia. Journal of Environmental Management 80:311-317.

[28] Hren, J and HR Feltz. 1998. Effects of irrigation on the environment of selected areas of the Western United States and implications to world population growth and food production. Journal of Environmental Management 52:353-360.

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

[30] Khan, S and MA 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.

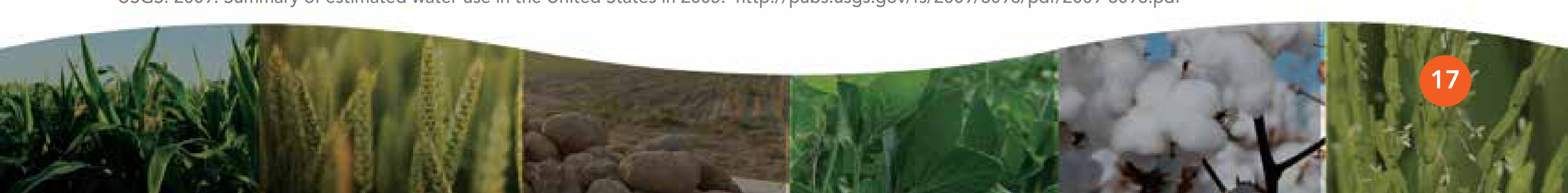
[31] USDA. 2004. Briefing Room; Irrigation and Water Use. Washington, D.C.: United States Department of Agriculture.

[32] World Commission on Environment and Development. (1987). Our Common Future. New York: United Nations.

[33] Khan, S and MA 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.

[34] 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.

[35] USGS. 2009. Summary of estimated water use in the United States in 2005. http://pubs.usgs.gov/fs/2009/3098/pdf/2009-3098.pdf



Field to Market also strongly recognizes the importance of annual rainfall and groundwater resources in providing context for irrigation decisions and the impacts of irrigation in a given geographic area[36] as well as the importance of different "types" of water – green, blue, and gray – and how their usage can impact water stress. The decision to irrigate will be driven in part by the geographic context, and the impacts of irrigation on the watershed will vary based on specific regional and local context, including water scarcity and availability, aquifer recharge rates, etc. For example, for aquifers such as the Ogallala, where withdrawals (for all uses, including agriculture) significantly outpace recharge rates, irrigation water applied must be compared against overall limitations to truly understand water sustainability issues for that region. Important work to characterize geographic variability and total water use indices is being developed by others; consistent with the scope and purpose of this current work, Field to Market focuses here on overall national trends.

This report focuses on total irrigation water applied as well as the incremental benefit of that irrigation water in terms of additional production achieved. Irrigation water applied is the anthropogenic application of water on land to facilitate the growing of crops, pastures and recreational lands in order to maintain vegetative growth.[37]

Although it is recognized that irrigation sources vary,[38] in this report, these differences will not be addressed; the focus of the report is on irrigation water applied, irrespective of source. 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.

Data used for the irrigation analysis for the report were taken from the "Farm and Ranch Irrigation Survey," part of the Census of Agriculture.[39 40 41 42] This data source was chosen because it is the only consistent and peer-reviewed source available for national data on water use and water management practices in the United States.[43 44 45] The benchmark years of data used in this analysis are 1984, 1988, 1994, 1998, 2003, and 2008. The reference year for the Farm and Ranch Irrigation Survey is generally the year following the general NASS Agriculture Census. Survey methodology included a mail-out survey to nearly 20,000 randomly selected operators who had noted irrigation use in previous census years. While participants were randomly selected, leading irrigation states were well represented. The population was stratified into Water Resource Area, state, and the number of irrigated acres in order to increase the probability that an operator would be selected based on irrigation usage.[46]

[37] USGS. 2008. Water Science for Schools; Irrigation Water Use. Washington, D.C.: United States Geological Survey.

[38] Chakravorty, U. and C. Umetsu. 2003. Basinwide water management: A spatial model. Journal of Environmental Economics and Management 45:1.

[39] 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. http://www.census.gov/prod/1/agr/92fris/

[40] 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. http://www.nass.usda.gov/census/census97/fris/fris.htm

[41] USDA NASS. 2002. 2003 Farm & Ranch Irrigation Survey. In: Census of Agriculture 2002. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. http://www.agcensus.usda.gov/Publications/2002/FRIS/fris03.pdf

[42] 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.

[43] Maxwell, SK, Wood, EC and A Janus. 2008. Comparison of the USGS 2001 NLCD to the 2002 USDA Census of Agriculture for the Upper Midwest United States. Agriculture, Ecosystems & Environment 127:141-145.

[44] USDA. 2008 Oct. Commodity Costs and Returns. Washington, D.C.: United States Department of Agriculture.

[45] Chang, T and PS Kott. 2008. Using calibration weighting to adjust for nonresponse under a plausible model. Biometrika 95:555.

[46] USDA NASS. 2008. Farm and Ranch Irrigation Survey. http://www.nass.usda.gov/census/census92/ag0300.htm.

This survey provides information on the sources and uses of irrigation water for 48 states, not including Hawaii and Alaska. Information obtained from survey participants included the source and amount of water used for irrigation, the number of acres irrigated, the type of distribution system used for irrigation, the number of wells and their characteristics, the amount of water use for each crop type, the average crop yields, the participant's irrigation practices, the capital spent on irrigation, the maintenance costs, the type of energy used, and the types of new technologies employed.

Data used from the Farm and Ranch Survey for this metric include quantity of water applied by crop, acres of irrigated crop, yield for the irrigated crop and yield for non-irrigated production on farms that irrigate. Given that the data presented in the Farm and Ranch Irrigation Survey are collected for farms that do irrigate we feel that it is appropriate for purposes of this analysis to compare the irrigated and non-irrigated yields on these farms and the differential between them. However, it is recognized that the reasons for irrigating or not irrigating are complex and often are not simply a matter of equal land capability class; this report assumes that the dryland comparison from the same farm provides a "control" condition that for various reasons may not provide a clean, unbiased comparison. For rice and potatoes, data for non-irrigated production are not available and consequently we consider the total yield to be attributable to irrigation, i.e., non-irrigated yield is assumed to be zero for calculation of the metric.

The national average yield for each crop (yields for farms that irrigate, including the irrigated and non-irrigated yields on these farms) was calculated by averaging the values for the six census years stated above. Using the averages of these six benchmark years, the relationship between the national average yield, irrigated yield and non-irrigated yield was established for each crop. National averages for irrigated and non-irrigated production, yield, and water use are based on state level acreage and water use weights. Then, by linear interpolation, the outcomes were used to estimate irrigated and non-irrigated yields and water applied per acre for years without census data. These years were based on annual data from NASS and their crop production report. In addition, the average share or portion of total acreage irrigated for each crop was calculated. This was done by dividing the amount of land irrigated by the total amount of land planted for each crop:

- *Irrigated acres/total planted area (acres) = irrigated share*

The share of irrigated acreage for reference years was used to estimate the irrigated acreage for non-survey years by linear interpolation. Between survey values, water application rates were estimated by linear interpolation; after 2008, they were assumed to be constant at the 2008 level.

Non-irrigated yield for farms that irrigate was subtracted from irrigated yield for farms that irrigate in order to determine difference in yield between the two practices(again, yields were only compared for farms that do irrigate; yields were not compared against farms that do not irrigate) Data were averaged over all six reference years before the overall differential was established:

- *Irrigated yield – non-irrigated yield = Net Impact of Irrigation on Yield*

The average amount of water applied is expressed in acre inches and divided by the irrigation yield differential to determine the acre inches of water used per unit of incremental production:

- *Total acre inches /difference in yield*

We recognize the limited number of data points as a limitation to our methods. However, at the national level, a suitable alternative was not found. Smaller scale studies may provide more regular annual data at the state or regional level. For the same reason, a small n value for reference years, statistical analyses for significance were not performed.

Results are presented in total irrigation water applied, irrigation water applied per planted acre, and irrigation water applied per unit of incremental production due to irrigation. Average trends for the entire study period are calculated using a least squares trends analysis. Efficiency data are indexed where the year 2000 equals 1 and displayed with other resource indicators on a summary spidergram by crop.

2.6. Energy Use Indicator

From the generation of electricity and production of nitrogen fertilizer to the drying and transportation of grain, agriculture uses energy in many forms. Numerous studies have estimated the energy use, both direct and indirect, from crop production (see Piringer and Steinberg 2006, Shapouri 2004, West and Marland 2002, and Lal 2004 for energy estimates and summaries of other studies).[47 48 49 50] However, these studies typically look at energy use at a point in time, rather than as a time-series, as we are doing in this study.

Our analysis includes the major energy intensive areas of on-farm crop production: direct usage including operation of farm equipment, pumping irrigation water, and crop drying utilizing various energy products (diesel, electricity, gasoline, natural gas, and liquefied petroleum gas) and indirect usage including fertilizer production and crop protectant production. Our analysis does not quantify the energy associated with manufacturing farm equipment or other structures such as grain bins, buildings, etc.; these items typically contribute very little to the total energy or greenhouse gases given that they last many years and are often recycled/scrapped at the end of their usable life.

Direct usage includes average energy use for irrigation and transportation to move the crop to on-farm storage and ultimately to the point of sale. The 2012 energy use indicator is more comprehensive than that in the 2009 report in many ways, among the changes are the inclusion of embedded energy in seed and the handling energy associated with manure. Other additions to the energy metric include corrections for power generation efficiency, crop drying, and crop transport.

This 2012 study also attempts to capture the efficiency improvements over time in off-farm processes such as nitrogen production and electric power generation. An example of these efficiency changes is the significant reduction in the amount of natural gas it takes to produce nitrogen fertilizer (according to Fertilizer Institute data through 2006).

Data from several USDA sources, as well as other sources, were used to build estimates of the total energy use by crop by year. At the heart of the analysis of the energy used to produce corn, soybeans, wheat, cotton, and rice are the USDA's Agriculture Resource Management (ARMs) surveys; such comprehensive data were not available for potatoes and thus some values were taken from university crop enterprise budgets and used where needed. Our study also draws data from USDA's Agricultural Chemical Usage reports as well as the Greenhouse Gas Regulated Emissions and Energy Use in Transportation (GREET 1.8d) model from Argonne National Laboratory. All energy requirements are converted into British Thermal Units (BTU) for comparison purposes. Greenhouse gas emissions and embedded energy values for pesticides are taken from a Cranfield University study titled "Estimation of the greenhouse gas emissions from agricultural pesticide manufacturing."

[47] Piringer, G and L Steinberg. 2006. Reevaluation of Energy Use in Wheat Production in the United States. Journal of Industrial Ecology 10: 1-2: 149-167.

[48] Shapouri, H, Duffield, J, McAloon, A and M Wang. 2004. The 2001 net energy balance of corn-ethanol. Washington, D.C.: United States Department of Agriculture. http://www.usda.gov/oce/reports/energy/net_energy_balance.pdf

[49] West, TO and 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.

[50] Lal, R. 2004. Carbon emission from farm operations. Environmental International 30 (2004) 981-990. http://cirit.osu.edu/clusterone/LASCANET/pdf%20files/Lal_3.pdf

[51] Audsley, E, Stacey, K, Parsons, DJ, Williams, AG. 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

2.6.1 Fuel and Electricity

The approach used to calculate fuel and electricity energy in the 2012 metric is very different than that in the 2009 report. The 2009 report used USDA estimates for the dollar value of all fuel- and energy-related expenses and used a price factor to estimate the physical quantity of the input used, often called a top down approach. The 2012 report uses a bottom up approach by which the estimate is built one piece at a time, e.g. using energy values for tractor operations, irrigation water pumping, grain drying and hauling, etc.

Several data sources are used to build these bottom-up estimates including the ARMs survey, the Farm and Ranch Irrigation Survey, and the Agricultural Census. These reports were used to establish levels of factors such as irrigation water applied, system pressure, and pumping water depth; all these factors allow for the creation of an estimate for pumping energy for irrigation. In the case of equipment operation, a combination of ARMs data on tillage practices as well as national level data for tillage practices from the Conservation Technology Information Center (CTIC) were used with data on energy consumption from NRCS and ERS. 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 the study by West and Marland.[52] Given that specific data for cotton and rice energy by tillage system were not provided in the West and Marland (2002) study, it was assumed the tillage contribution to be the same for cotton as for corn for a given system, e.g., no-till.

In the case of rice, USDA NRCS estimates for fuel consumption[53] for rice versus corn were used to calibrate the West and Marland estimates to rice; corn was chosen because the USDA NRCS calculator includes estimates for corn in all states that also produce rice and is also found in the West and Marland study.

The national average rice tillage energy for a conventional tillage program was 54% that of corn among rice producing states. The portion of planted acreage managed using each of the defined tillage systems comes from the ARMS data and CTIC and is available for all crops with the exception of potatoes which are assumed constant over time.

Ideally, data would exist to allow quantification of fuel efficiency and emissions changes over time; however, our scan of the U.S. agriculture landscape did not find such data and consequently fuel efficiency over time is considered constant. We acknowledge that while not reflected in this analysis, equipment technology such as advanced transmissions and performance optimization have improved fuel efficiency per acre and per unit production.

Fuel use data are not available through ARMS for potatoes, and consequently placeholder values were used based on typical levels provided in a detailed, 2006 University of Idaho study of production costs for Idaho potatoes:[54]

- Fuel for custom fertilizer applications (2), and custom aerial sprays (3) – 1.7 gallons of diesel/planted acre/year (set value for all years)
- Fuel for custom soil fumigation operations at 4.78 gallons of diesel/acre corrected by the percent of acres fumigated in "program states" each year
- Fuel use for other tractor operations (such as land prep, tillage, harvest) at a set value of 27.23 gallons of diesel/acre/year and 3.19 gallons of gasoline/acre/year
- Custom hauling was calculated at 0.07 gallons of diesel/cwt using production volume from each year

[52] West, TO and 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

[53] USDA NRCS Energy Estimator. Energy Consumption Awareness Tool: Tillage. http://ecat.sc.egov.usda.gov/

[54] Patterson, PE and RL 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

The 2012 report also makes an estimate of the energy associated with manure application by crop: the report uses ARMS data for application rate, incidence of application and animal species to estimate the loading and application energy used for manure. 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.

2.6.2 Agricultural Chemicals (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.[55] USDA ARMS data utilizes 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 provided in a report titled "Estimation of the greenhouse gas emissions from agricultural pesticide manufacturing" (Cranfield University, United Kingdom); the Cranfield study provides factors for energy and greenhouse gas emissions for the three named USDA pesticide categories (herbicides, insecticides, fungicides).[56] Fumigant, Plant Growth Regulators, Defoliants and other pesticide greenhouse gas (GHG) and energy values are not available in the Cranfield report; 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 by crop over time.

Product average values used for all crops/all years were as follows, as derived from the Cranfield study:[57]

- 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

2.6.3 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.[58] 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, one can calculate fertilizer per planted acre. Dividing by USDA's yield data results in the amount of fertilizer per bushel or pound of crop. Fertilizer application rates for N,P_2O_5, and K_2O basis are multiplied by energy conversion factors provided in the GREET 1.8d model; these factors include embedded energy and transport energy for fertilizer. Values used for all crops are as follows:[59]

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

Note: Corn, cotton, potatoes, rice and wheat all require fertilizer nitrogen for economically viable yields. When properly inoculated, soybeans do not require nitrogen fertilizer. However, diammonium phosphate (DAP) is one of the most common forms of phosphorus fertilizer and it contains nitrogen. Thus, any DAP applied to soybeans will include nitrogen. It is this portion of nitrogen that is included in the soybean calculations.

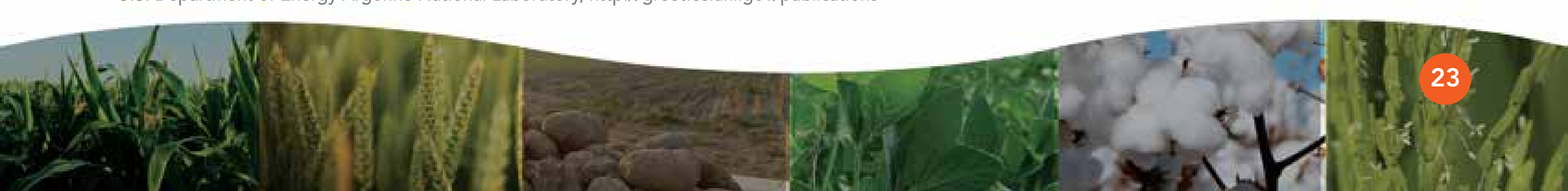
55 USDA National Agricultural Statistics Service (NASS). 2011. Agricultural Chemical Usage – Field Crops and Potatoes. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1560

56 Audsley, E, Stacey, K, Parsons, DJ and AG Williams, AG. 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

57 Ibid.

58 USDA ERS. 2008. Nitrogen used on cotton, rate per fertilized acre receiving nitrogen, selected States. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://www.ers.usda.gov/Data/FertilizerUse/Tables/Table16.xls.

59 U.S. Department of Energy Argonne National Laboratory, http://greet.es.anl.gov/publications



2.6.4 Planting Seed Energy

Seed energy, or more specifically, energy in seed used for crop establishment, is estimated as a proportion of the crop that would need to be used to create the seed used to establish the crop. Using corn as an example and given its relatively high yield and relatively low seed planting rate per acre, the impact of planting seed energy on total energy is very minimal. Also included in the seed calculation are 2 factors that are held constant across all crops which are the seed production yield factor (0.66) and the seed production energy intensity factor (1.5). These factors are used to correct for the fact that seed yields are typically lower than the crop yield for grain and also that more inputs are typically in the production of seed versus the general crop. In effect the factors imply that seed yields are 66% that of production for the general market and that input usage (fertilizer, tillage, etc.) is 150% that of commercial production. No official source exists for these seed factors so 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. The impact of this approach likely creating a high estimate is minimized by the fact that seed usually accounts for less than 2 or 3 percent of the total energy to produce the crop.

Corn Seed Calculation		
Grain Yield	150	Bushel per Acre
Seed Yield Factor	0.66	Percent of Grain
Seed Yield	99	Bushels per Acre
Seed Input Intensity Factor	150	Percent
Seed Use Rate	25895	Kernels
Seed Conversation	80000	Kernels/Bushel
Seed Energy Share	0.49	Percent

2.6.5 Drying and Crop Transport

Drying and crop transport energy was estimated by drawing estimates of grain drying activity from USDA reports, and in some cases extension specialists, and applying formulas available from extension literature.[60] The amount of moisture removed from grain and cotton were considered to be constant over time (does not change from year to year) as were the thermal efficiencies of drying equipment, this assumption was used with recognition that newer, more energy efficient grain dryers are being installed but that there is a lack of publicly available data to account for these improvements over time. Estimated distances from farm to point of sale were used in conjunction with EPA data on fuel consumption of heavy trucks to develop the transportation estimate.[61] Estimated distances are provided in the table below and are based on expert judgment regarding the crops analyzed; actual data are not available through the published ARMS surveys. EPA reports average one-way heavy truck mileage at 6.5 miles per gallon of diesel and provides no guidance on energy efficiency or emissions changes over time. Consequently this value is held constant over time. Literature on the amount of moisture removed from crops and the average distance transported is not routinely reported in the ARMs data or elsewhere. Given the lack of publicly available data at this time, both drying and transport energy levels are held constant on a per unit of production basis.

	Points of Moisture Removed	One-Way Distance Transported-Miles
Corn	2.9	30
Soybeans	1.4	45
Wheat	1.4	45
Rice	5.0	30

[60] 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

[61] United States Environmental Protection Agency. 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.

2.6.6 Transport and Storage Energy Use (Potato)

Depending on the sales arrangement a grower has with his/her buyer, potatoes may be sold as delivered to the buyer's location or the burden of hauling may be the responsibility of the buyer. In our analysis we don't include any transport energy from the farm or farm storage to the buyers' location.

Much of the fall potato crop is stored after harvest. This is to achieve year-long supply for the fresh market and to make efficient use of the capital investment in processing facilities. Storage energy is used for cooling and for air circulation to prevent excess build-up of humidity and/or CO_2. However, time in storage differs significantly, ranging from a few weeks to 10 months. In the case of potatoes, for this report, the crop was considered to have been stored for 120 days on farm and no transportation energy was assigned to the crop for purposes of this analysis.

Energy for ventilation in storage ranges from 7-13 kWh/1000cwt/day with conventional fans and from 3.7 to 7.2 Kwh/1000cwt/day with variable fan drives. For 120 days of storage, those ranges represent 2.7-5.1 KBTU/cwt and 1.5 to 2.9 KBTU/cwt respectively. These values are in the range of 2.8 to 9.7 percent of the total energy for production of the crop.

Energy use for cooling of stored potatoes varies greatly with the ambient temperature, which changes with the time of the year and with location. 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.

Results are presented as total resource use (total Btu), average energy use per acre, and energy use per unit of production. Average trends for the entire study period are calculated using a least squares trends analysis. Efficiency data are indexed where the year 2000 equals 1 and displayed with other resource indicators on a summary spidergram by crop.

2.7. Greenhouse Gas Emissions Indicator

Climate change and its potential impact on agriculture is an important public policy topic. U.S. agriculture is a small but significant source of greenhouse gas, roughly 6.5% according to the US EPA.

This report measures the carbon dioxide equivalents (CO_2e) emitted both directly and indirectly in the production process. Whenever practical, the methods used in our greenhouse gas emission calculation utilize the US EPA inventory of emissions, including factors such as field burning and residue removal which were not included in the 2009 report.[62,63,64] This report also takes co-product/bi-products into consideration in the calculation of all metrics including energy and greenhouse gases. In the national context, cotton and wheat are the only two crops impacted by co-products in this analysis.

According to much of the current literature, energy use and tillage create sources of greenhouse gas emissions. However, some agricultural practices have the potential to sequester carbon dioxide in the soil.[65,66] For example, continuous no-tillage practices for some crops are documented as sources of carbon sequestration.[67,68] However, national scale datasets regarding continuous no-till practices do not exist, and the impact of intermittent no-till or other conservation tillage practices on soil organic matter remains poorly understood and are soil and climate specific. Some studies suggest that no-till may result in changes in the distribution of soil carbon—concentrating it into the upper-most soil layer— rather than a significant increase in total soil carbon measured over a larger soil profile.[69,70] We recognize these uncertainties in the current scientific understanding of the impacts of tillage practices as limitations to our greenhouse gas emissions methodology and for these reasons soil carbon change is not counted in our greenhouse gas emissions indicator for 2012; our previous work did include it as an offset against other emissions. The removal of soil carbon from our metric is not an indication of lack of importance but rather an acknowledgment of the complexity and uncertainty of its measurement.

[62] U.S. Environmental Protection Agency. 2012. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. Chapter 6: Agriculture. Washington, D.C.: U.S. Environmental Protection Agency. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

[63] U.S. Environmental Protection Agency. 2011. Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options. A Report of the EPA Science Advisory Board. Washington, D.C.: U.S. Environmental Protection Agency. http://yosemite.epa.gov/sab/SABPRODUCT.NSF/67057225CC780623852578F10059533D/$File/EPA-SAB-11-013-unsigned.pdf

[64] Ibid.

[65] Snyder, CS, Bruulsema, TW, Jensen, TL and PE Fixen. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agric. Ecosyst. Environ. 133: 247–266.

[66] Paustian, K, Andren, O, Janzen, HH, Lal, R, Smith, P, Tian, G, Tiessen, H, Van Noordwijk, M and PL. Woomer. 2007. Agricultural soils as a sink to mitigate CO2 emissions. Soil Use and Management 13:s4:230-244.

[67] For example, West, TO and W.M. Post. 2002. Soil organic carbon sequestration by tillage and crop rotation: A global data analysis. Soil Science Society of America Journal 66:1930-1946.

[68] Ibid.

[69] Omonode, RA, A Gal, E Stott, TS Abney and T J Vyn. 2006. Short-term versus continuous chisel and no-till effects on soil carbon and nitrogen. Soil Science Society of America Journal 70: 419-425.

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

Another significant change in the 2012 report comes with the addition of rice as a crop. Methane emissions are associated with rice production. CH_4 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. Because the 2009 report did not include rice, it did not include methodology for estimating CH_4 emissions; this methodology is now incorporated in the case of rice.

Estimates for emissions from equipment operation and other operations such as irrigation pump operation were developed in the same manner as in the energy calculation and a factor of 22.3 pounds CO_2 per gallon of diesel combusted was used. It is expected that actual emissions associated with combustion of diesel through agricultural engines has improved over time but no time series data for these emissions exists at this time. It is our understanding that groups such as the Nebraska Tractor Testing Laboratory are starting to track emissions of new equipment entering the agriculture sector and in the future these data can be used to substantiate change over time.

2.7.1 Agricultural Inputs

Data from the USDA's Agricultural Chemical Usage report provided periodic benchmarks for both chemical usage and fertilizer use for all crops in the 2012 study.[71] These product application rates were interpolated between reference years on a rate per acre basis to fill in gaps in data. Emissions factors for product-embodied CO_2 were taken from the GREET model version 1.8d for fertilizer and from Cranfield for crop protection products.[72] [73]

These emission factors were further adjusted to account for efficiency changes over time for natural gas to ammonia fertilizer conversion in the case of 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 very high relative importance of electric power in the production of these products compared to other energy inputs according to Cranfield.

The embedded greenhouse gases in the seed used to produce the crop is estimated in the exact same manner as it is for energy, e.g, as a fraction of the total greenhouse gases to produce the crop. A simplistic example would be if it takes 1 bushel of seed to plant a crop that produces 100 bushels of grain, then the greenhouse gases are roughly 1/100 or 1%. Expansion factors were applied to this 1% to acknowledge that seed yields are typically less than grain yields and that input use on seed is likely somewhat higher than grain production alone. An estimate of the fraction of the crop used to create the seed is developed and the emissions are based on the emissions to produce the actual crop.

[72] U.S. Department of Energy Argonne National Laboratory, http://greet.es.anl.gov/publications

[71] USDA National Agricultural Statistics Service (NASS). 2011. Agricultural Chemical Usage – Field Crops and Potatoes. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1560

[73] Audsley, E, Stacey, K, Parsons, DJ and Williams, AG 2009. Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. Bedfordshire, U.K.: Cranfield University. https://dspace.lib.cranfield.ac.uk/bitstream/1826/3913/1/Estimation_of_the_greenhouse_gas_emissions_from_agricultural_pesticide_manufacture_and_use-2009.pdf

2.7.2 Emissions from Machinery Operations

The carbon emissions due to equipment operation for alternative tillage systems were reported by West and Marland (2002) as follows:[74]

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

The three tillage systems are defined in the study as being consistent with the definitions used by the Conservation Technology Information Center (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.[75] USDA ARMS data are used for rice; conventional tillage 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.[76]

Conventional tillage uses the most energy for machinery, and hence produces the largest carbon emissions of the three practices (no-till, reduced tillage, and conventional tillage), with respect to machinery usage. No-Till uses the least amount of energy, and hence produces the least amount of carbon emissions (see Table 2.7). Given that specific data for cotton and rice emissions by tillage system were not provided in the West and Marland (2002) study, it was assumed the tillage contribution to be the same for cotton as for corn for a given system, e.g., no-till.

In the case of rice USDA NRCS[77] estimates for fuel consumption for rice versus corn were used to calibrate the West and Marland estimates to rice; corn was chosen because the USDA NRCS calculator includes estimates for corn in all states that also produce rice and is also found in the West and Marland study. The national average rice tillage energy for a conventional tillage program was 54% that of corn among rice producing states. The portion of planted acreage managed using each of the defined tillage systems comes from the ARMS data and CTIC and is available for all crops with the exception of potatoes which are assumed constant over time.

The analysis in this report assumes that these emissions factors by tillage system have not increased or decreased over time. According to researchers at the Nebraska Tractor Test, the focus of agricultural engine researchers has been to reduce emission and this focus has limited their progress in fuel consumption improvements over time. Other recently added performance improving attributes of farm tractors are not well captured in the data provided by USDA.[78] While the specific impact of this assumption is not known, the directional impact is likely an understatement of improvements in energy efficiency and associated emissions over time.

Changes over time in the national average emissions from machinery come only from the changing percentages of tillage practices over time. Efficiency gains due to changes in tillage practices are captured using the CTIC and ARMs data for the share of each crop under each tillage system. In the case of potatoes, no change in tillage-related energy was assumed over the study period. This assumption was made because no publicly available data could be found to substantiate change over time.

[74] West, TO and 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.

[75] 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

[76] Patterson, PE. 2004. Cost of Potato Production Comparisons for Idaho Commercial Potato Production. Moscow, Idaho: University of Idaho College of Agricultural and Life Sciences, Department of Agricultural Economics and Rural Sociology. http://www.ag.uidaho.edu/aers

[77] USDA NRCS Energy Estimator. Energy Consumption Awareness Tool: Tillage. http://ecat.sc.egov.usda.gov/

[78] Personal communication.

Emissions associated with changes in the level of soil carbon are considered to be neutral in this study so they neither add nor subtract from the total emissions of the crop.

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.

2.7.3. Soil Nitrous Oxide (N_2O) Emissions from Nitrogen Application

Nitrous oxide (N_2O) is a potent greenhouse gas (global warming potential 296 times CO_2),[79] and as such, N_2O released from soil microbial activity in association with fertilizer nitrogen application is an important source of carbon-equivalent emissions. However, the range of estimates for N_2O as a percent of N applied is very wide depending on the source of N, the method of application, and the soil conditions at the time of application. Data from the 2009 International Plant Nutrition Institute literature review reports that N_2O emissions as a percent of N applied can range from near zero to nearly 20 percent of applied N.[80] Bouwman et al (2002) report a global mean of 0.9% of nitrogen from fertilizer is released from soil as N_2O.[81]

For the purposes of our analysis we use a factor of 1.4 percent of all fertilizer N applied. This estimate is consistent with the current Intergovernmental Panel on Climate Change (IPCC) estimates.[82]

To estimate N_2O emissions from crop production the applied nitrogen from commercial/synthetic fertilizer and manure is multiplied by 1.4 percent to estimate the nitrogen that is emitted as nitrous oxide.

The 1.4 percent factor accounts for emissions from all sources, both direct and indirect. The IPCC assumes that 1% of applied nitrogen fertilizer (uncertainty range of 0.3-3.0%) is lost from direct emissions of N_2O at the field level due to nitrification/ denitrification. This assumption is based on analysis of all appropriate scientific publications that report these losses for specific crops and cropping systems (IPCC, 2007a). Indirect N_2O emissions result from denitrification of volatilized ammonia (NH_3) deposited elsewhere or from nitrate (NO^3) - lost to leaching and runoff as the reactive nitrogen (Nr) cascades through other ecosystems after leaving the field to which it was applied. The IPCC assessment protocol assumes that volatilization losses represent 10% of applied nitrogen, and that N_2O-N emissions for these losses are 1% of this amount; leaching losses are assumed to be 30% of applied nitrogen and N_2O-N emissions are 0.75% of that amount.[83] Therefore, the IPCC default value for total direct and indirect N_2O emissions represents about 1.4% of the applied N from fertilizer. While sophisticated models exist to more closely estimate N_2O emissions on a field scale (e.g., the DeNitrification-DeComposition, or DNDC model),[84] the execution and aggregation of this model to the national scale is beyond the scope of this report, and for the purposes of estimating trends in national average emissions, the use of the single factor is deemed appropriate.

[79] 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, JT,Ding, Y, Griggs, DG, Noguer, M, van der Linden, PJ, Dai, X, Maskell, K and CA Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

[80] Snyder, CS, Bruulsema, TW, Jensen, TL and PE Fixen. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agric. Ecosyst. Environ. 133: 247–266.

[81] Bouwman, AF, Boumans, LJM and NH Batjes. 2002. Modeling global annual N2O and NO emissions from fertilized fields. Global Biogeochemical Cycles 16:4:1080.

[82] IPCC. 2001. IPCC Third Assessment Report: Climate Change 2001. Geneva: United Nations Environmental Program Intergovernmental Panel on Climate Change. http://www.grida.no/climate/ipcc_tar/wg1/

[83] 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

[84] DNDC Biogeochemistry Model, http://www.dndc.sr.unh.edu/

Data on U.S. mean annual fertilizer nitrogen applied per crop by year is provided by USDA and manure application data were taken from USDA's ARMS data concerning tons applied and manure source by crop over time. Data for 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. It is noted that management factors such as split application on nitrogen as well as application method and timing can have a 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.

To convert the emissions from applied nitrogen into carbon dioxide equivalents (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 N results in emission of 651 pounds CO_2e.

- *Emissions from 100 pounds applied N = 100 X 1.4% X (44/28) X 296 = 651 pounds CO_2e.*

2.7.4 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 but in cases where residue is burnt the impact can be significant. Field burning emissions are calculated for all crops in the study except potatoes due to the fact that potatoes typically have no surface residue that would warrant burning; while we have algorithms to estimate emissions from burning for soybeans and cotton and these are utilized in this report, from a practical standpoint little or no field burning is performed for these crops. National incidence levels of residue burning are taken directly from the EPA reporting of greenhouse gases from agriculture. 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 CH_4 and N_2O released into the atmosphere.

The release of CO_2 is not counted as it is expected to be released over time independent of burning; burning just changes the timing. At the national level, field burning of sugarcane is a much larger contributor than any of the crops considered in our analysis. Among the crops in our analysis burning of rice residue is the most prevalent with 10% of acres being burnt according to EPA data. When you apply the factors to calculate emissions from residue burning of rice overall it accounts 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 have residue removed following the primary crop harvest. A value of 0.21 pound N from residue per bushel of grain harvested times the amount of acres harvested for straw of wheat harvested is subtracted from the greenhouse gas accounting. According to 1998 USDA ERS data, 13% of all wheat acres experience straw removal; the nitrogen factor is based on an expectation of 50% of the surface residue being removed. At the national level wheat straw removal reduces greenhouse gas emissions for the crop by between 0.5 to 0.75 percent.

2.7.5 Methane (CH_4) Emissions from Rice Fields

Emissions for rice are based on the levels reported in the EPA's annual inventory of greenhouse gases.[85] EPA 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 EPA's reporting of the data, CH_4 emissions have trended lower over time on both a per acre and per unit of production basis. It should be noted that CH_4 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.

2.7.6 Emissions from Grain Drying and Transport

The emissions from grain drying, crop storage (potatoes), and transport are calculated in a consistent manner with the energy used for these activities. Largely the amount of fuel energy combusted and electricity consumed are used to estimate greenhouse gas emissions. Propane is assumed as the fuel 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.

Results are presented as total greenhouse gas emissions (carbon dioxide equivalents), average emissions per acre, and average emissions per unit of production. Average trends for the entire study period are calculated using a least squares trends analysis. Efficiency data are indexed where the year 2000 equals 1 and displayed with other resource indicators on a summary spidergram by crop.

[85] U.S. Environmental Protection Agency. 2012. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2010. Chapter 6: Agriculture. Washington, D.C.: U.S. Environmental Protection Agency. http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

2.8. Discussion of Progress on Water Quality and Biodiversity Indicators

Introduction

In its 2009 environmental indicators report, Field to Market recognized the need to develop methodologies for measuring environmental outcomes of water quality and biodiversity. Field to Market has been working actively since that first report to develop metrics for these outstanding indicators. Each has posed unique challenges and greater difficulty as compared to the indicators detailed in the first report, raising important questions, in particular, about what trends can be reported at the national or regional scale that are meaningful, measurable, and can be correlated back to practices and decisions within the control of agricultural producers.

Below we describe our progress in developing metrics for water quality and biodiversity at the national and regional scale. Field to Market plans to report on an analysis of watershed-scale trends in water quality and aquatic biodiversity (currently under review) in the future. Field to Market is also currently actively developing and evaluating potential field and farm-scale metrics for water quality and biodiversity and will release information about these processes and products as appropriate in the future.

In the past several years, the USDA Conservation Effects Assessment Project (CEAP) has provided important analyses of regional and national water quality and biodiversity trends. CEAP is a multi-agency effort to quantify the environmental effects of conservation practices and provides the science and education base needed to enrich conservation planning, implementation, management decisions, and policy.

Recent CEAP Cropland National Assessment reports for specific river basins have provided findings regarding trends in implementation of conservation practices for soil erosion control and nutrient management; the modeled or estimated impacts of these practices in reducing sediment and nutrient losses; and the predicted benefit of additional implementation. The CEAP Wildlife National Assessment similarly seeks to quantify fish and wildlife benefits of conservation practices. [86]

[86] USDA Natural Resources Conservation Conservation Service. 2012. Conservation Effects Assessment Project. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap

Water Quality

Water quality is recognized as a primary concern for all agricultural stakeholders – including producers, the supply chain, consumers, conservation organizations, and regulatory agencies. The impacts of agriculture on water quality and aquatic ecosystems have been extensively studied and discussed. At the broad scale, Field to Market's effort to contribute to existing analyses and dialogues has focused on evaluating correlations between agricultural land use, water quality, and aquatic biodiversity at the watershed scale using publicly available monitoring datasets. This has proven no easy task, especially given the complexity of environmental and anthropogenic processes within a watershed. The work has been conducted under the leadership of University of Arkansas, with technical support, peer review, and directional guidance from the USGS as well as from water quality experts within Field to Market's diverse membership. The analysis is currently under review and information will be shared when final results are available.

Field to Market is also currently actively exploring potential field and farm-scale metrics for water quality to be implemented in the Fieldprint Calculator.

Biodiversity

Field to Market continues to explore indicators for biodiversity as related to agricultural sustainability. According to 2007 land use data from the USDA, the United States composes 2.3 billion acres in total; 17.7% of these are cropland, or 406 million acres.[87 88] In addition to working croplands, farmers also own and manage non-working lands including pastures and forests. Together, these working and non-working agricultural lands provide important ecosystem services including food production, habitat, soil health and prevention of soil erosion, and maintenance of water quantity and quality (which can also provide positive benefits for aquatic biodiversity). Private lands account for one quarter of the total populations of imperiled and endangered species in the U.S.[89] As the supply chain and consumers become more interested in the footprints of their food, including its impacts on biodiversity and the ecosystem services provided by agriculture, numerous efforts have emerged to develop biodiversity metrics and life cycle assessments for agricultural production.

A first path toward meeting production and biodiversity goals is in maintaining and increasing productivity of existing agricultural lands rather than expanding to/converting lands not already in production, thus decreasing pressure on existing habitat for wildlife and biodiversity of all forms.[90] Field to Market's existing land use metric tracks progress in increasing productivity with respect to land use by calculating the amount of land needed to produce a unit of production (e.g., a bushel of corn).

[87] Lubowski, RN, Vesterby, M, Bucholtz, S, Baez, A and M.J. Roberts. 2006. Major Uses of Land in the United States, 2002. United States Department of Agriculture, Economic Research Service; Report nr EIB-14.

[88] 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. Washington, D.C.: United States Department of Agriculture.

[89] Stein, BA, Kutner, LS, Adams, JS. 2000. Precious Heritage: Status of Biodiversity in the United States. Oxford University Press.

[90] Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Washington D.C.: Island Press. http://www.millenniumassessment.org/documents/document.356.aspx.pdf

Within a relatively mature agricultural system, a key question posed by Field to Market has been how to maintain and increase productivity on agricultural lands while also maximizing opportunities for biodiversity. Specifically, for working lands, are there measurable mechanisms for promoting biodiversity that are also consistent with sustained production? In addition, are there mechanisms and practices that can be applied to marginal agricultural lands that also meet these objectives?

Field to Market recognizes that on the one hand, farms have demonstrated that they are compatible with many forms of biodiversity and ecosystem services, and many farmers actively manage for these services, for economic reasons or otherwise. On the other hand, management for biodiversity and wildlife can be inconsistent with production goals, especially when this management attracts potential pests or otherwise leads to decreased productivity.

Field to Market seeks to develop metrics and tools intended to help understand the overall progress of agriculture with respect to biodiversity and to enable individual growers to understand their own performance in this area and identify potential mechanisms for maximizing biodiversity while maintaining or improving productivity.

Since the fall of 2008, Field to Market has explored possible outcomes-based, science-based approaches to both tracking the overall progress of agriculture with respect to biodiversity and enabling individual growers to track and improve their own progress in this area.

Several challenges have consistently presented themselves, including:

- Identifying the appropriate scales to meaningfully measure biodiversity so that producers can use information in their day-to-day management and stakeholders can assess overall biodiversity conservation performance.
- Identifying long-term, large-scale, outcomes-based datasets. While remote sensing can provide habitat data, few large-scale, outcomes-based species datasets exist.
- Identifying a suite of indicators, based on biodiversity goals.
- Defining "sustainability" for biodiversity can be context specific, with competing definitions depending on biodiversity goals. For example, high species richness may be favorable in some contexts but not in others; actions favoring one species may help or harm another species; species to be explored can include indicator species, keystone species, umbrella species, flagship species, and vulnerable species.
- Linking broader impacts to farm-scale practices can be problematic due to "noise" created by other influences on biodiversity (e.g., population trends for wide-ranging species such as birds are impacted by non-agricultural land uses).

In light of these challenges, Field to Market has explored various mechanisms for measuring biodiversity outcomes that are meaningful, measurable, and within the individual farmer's ability to control. We have considered approaches focused on species richness and abundance, land cover type and quality, conservation practices, and ecosystem services.

Examples of approaches that Field to Market has explored or is currently exploring:

Broad Scale Trends:

- Regional trends in aquatic macroinvertebrates are being explored through Field to Market's work in water quality metrics. Using USGS NAWQA data and US EPA wadeable streams data, Field to Market is exploring trends in observed versus expected (O/E) ratios for aquatic macroinvertebrates in watersheds that are dominated by agricultural land use. Field to Market plans to share results of these studies in the future once they are finalized.
- Agricultural land use trends are reported through Field to Market's current Land Use indicator, which tracks trends over time for total land use and land use efficiency for many commodity crops. The efficiency measure reflects trends in increasing productivity that can reduce pressure to convert new habitat.
- Field to Market also has explored the efficacy of measuring broad-scale trends over time for terrestrial species. These investigations have been challenged by the availability of large-scale, long-term, comprehensive datasets. The Breeding Bird Survey provides a good example of such a dataset, but analyses of this data are limited by many of the challenges noted above, including the challenge of analyzing large scale trends in migratory bird patterns with respect to agricultural vs. other land use patterns.

Field and Farm-Scale Tools:

- Field to Market has been working with North Carolina State University to develop a field-scale proof of concept model that predicts the relationship between management actions and vertebrate species richness. Field to Market is currently evaluating the proof of concept results to determine next steps.
- Field to Market is also exploring the potential to develop a farm-scale index for land quality and conservation potential that would evaluate farm land types and the quality or conservation value of these lands.

3. Results

3.1. Results Overview

This section provides an overview of results for all crops followed by more detailed summaries for each crop. For each crop, each resource indicator is presented in three ways – resource use/impact per unit of production ("efficiency"), resource use/impact per acre, and total resource use/impact. Each provides important information with respect to sustainability, and the interpretation of each should be accompanied by certain caveats, as described below:

1. "Efficiency" indicators showing resource indicator (use or impact) per unit of production. "Efficiency" measures show change in use or impact over time relative to our ability to meet productivity demands and normalizes the metrics to a common unit of comparison for producers and stakeholder. Field to Market has highlighted these efficiency indicators as a unique and important piece of the sustainability conversation, especially to the extent that sustainability, as we have defined it, includes meeting both productivity and environmental goals. However, it should be noted increased efficiencies may still be accompanied by increased demand and increased production, and a complete conversation on sustainability requires an understanding of efficiency along with total resource constraints, uses, and impacts. Furthermore, other "efficiency" metrics, beyond units of production, may be desirable; for example, resources per calorie or other nutritional measure.

2. Per acre resource use or impact. Per acre resource use similarly normalizes the metrics to a common unit of comparison. For several resource indicators (e.g., land use, soil erosion, and irrigation water applied), resource use per acre is perhaps the most commonly encountered format. It should be noted however, that an equal amount of resources may be used per acre with varying production levels achieved, and thus the acre is itself a resource rather than an outcome. "Efficiency" indicators are an important mechanism of comparing resource use against the production outcome associated with acreage rather than the acreage itself.

3. Total use indicators show the annual use or impact per acre multiplied by total acres harvested. Total resource use or impact indicators are essential for informing conversations regarding total resource restraints or limits, however it should be noted that at the national level, important caveats should be placed around interpretation of total use metrics. First, total use does not necessarily equal total impact, as impact is created through interaction of resource use, resource constraints, and other factors. Second, resource limitations or constraints and thus impacts for many indicators are often more appropriately defined at the regional or local scale (e.g., soil erosion relative to soil regeneration rates, or irrigation water applied relative to aquifer recharge rates or streamflow), and thus total use values, particularly for some indicators such as water and soil, may have less meaning at a national level. Third, total use analysis for an individual crop may be impacted by changes in land use patterns for that particular crop and thus an aggregated understanding of total use across all crops may be a more meaningful metric for total use. Finally, lacking meaningful context of actual resource constraints against which to compare and normalize interpretations, total use data may be particularly misleading – for example, because total use for one crop is offset by another, or because an improving trend at a national level does not reflect real and significant challenges and impacts at a more local level. For these reasons, while total use data and results are presented in this report, the reader is cautioned that further analysis and context –which is currently beyond the scope of this report – is necessary to better understand the true impacts of total resource impacts in any given region or locale.

As discussed earlier in the methods section, results are expressed graphically in three forms:

1. A summary table of percent change over the full study period (based on a least squares trend analyses from 1980-2011) for each crop, indicator, and unit of analysis, found in the summary of results for each crop. Average trends for the entire study period are calculated using a least squares trends analysis.

2. A summary spidergram for "efficiency" indicators over time, found in the summary of results for each crop. The spidergram visually demonstrates the change in the overall efficiency footprint or "Fieldprint" over time and summarizes all indicators on one graph. In order to facilitate comparison and evaluate relative changes over time across multiple indicators with differing units of measure (e.g., Btu for energy vs. CO_2e), each efficiency indicator is indexed where actual values observed in the year 2000 are set equal to 1. Therefore, a 0.1 unit change in the index value of an individual indicator is equal to a 10% percent change relative to the actual value in the year 2000. Trends that demonstrate movement toward the center of the spidergram (toward a value of zero, or a shrinking of the "Fieldprint") represent an improvement of efficiency, or resource use/impact per unit of production, over time.

3. Individual line graphs for each crop, indicator, and unit of analysis (production, acre, and total) are also found in each crop summary section. The graphs chart actual resource values (e.g., actual Btu per bushel) by year for the entire study period (1980-2011). The line graphs provide additional resolution regarding changes over time and the conformity of those changes with average trend line for the full study period. The summary narratives also note where the data demonstrate a more recent deviation from the average trend line for the full study period. Note: The regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

Results are also highlighted and discussed in text for each crop and indicator. It should be noted that in both the results and conclusions sections, we have purposefully avoided speculation regarding the practice, contexts and drivers that influence the outcomes estimated through this analysis. Field to Market recognizes that management decisions by U.S. agricultural producers are guided by many factors, including availability of science and technology, price signals and other economic conditions, Farm Bill policies and programs including 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 interpretation, including at the more geographically-specific scale needed to understand some trends, is beyond the scope of this report. Please see the Discussion and Conclusions section for suggestions and considerations for future analyses and evaluations.

It should also be emphasized that average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted in the text. The national average trends, of course, may obscure local or regional variability on any given indicator. Finally, where actual numeric values are cited for each crop and indicator – for example, acres of land, acre inches of water, tons of soil erosion, Btu of energy, and CO_2e of greenhouse gas emissions – it should be noted that Field to Market has attempted to estimate values with the highest degree of accuracy possible given the national scope of the exercise, the availability of appropriate datasets, and the current state of scientific research and consensus. However, national scale data availability and/or current scientific knowledge may limit the accuracy of the actual values to some degree. Given the overarching objective of this analysis in examining changes in trends over time, the reader is encouraged to interpret the actual values as best approximations while understanding that the application of consistent methodology over time ensures the appropriate comparison of trends.

Environmental Indicators: Results Overview

Over the study period (1980-2011), on average at the national scale in the United States, the following trends were observed. Percent change is relative to single crop and based on the average trend line for the entire study period:

- **Production and Yield**
  - o Total production increased for corn (+101%), cotton (+55%), potatoes (+30%), rice (+53%), and soybeans (+96%); total wheat production decreased (-16%).
  - o Yield per planted acre increased for all crops: corn (+64%), cotton (+43%), potatoes (+58%), rice (+53%), soybeans (+55%), and wheat (+25%).
- **Land use**
  - o Land use per unit of production (e.g., bushels, cwt and pounds) has improved (decreased) for all six crops because of increased yields: corn (-30%), cotton (-30%), potatoes (-37%), rice (-35%), soybeans (-35%), and wheat (-18%).
  - o Total land use (planted acres) has increased for corn (+21%), cotton (+11%), rice (+9%) and soybeans (+24%) but decreased for potatoes (-15%) and wheat (-33%).
- **Soil Erosion**
  - o Soil erosion per unit of production has improved (decreased) for all six crops: corn (-67%), cotton (-68%), potatoes (-60%), rice (-34%), soybeans (-66%), and wheat (-47%).
  - o Per acre soil erosion has improved (decreased) for corn (-43%), cotton (-50%), potatoes (-34%), soybeans (-41%), and wheat (-34%) and remained constant for rice (rice has historically had low rates of soil erosion). However, improvements in per acre soil erosion for corn, cotton, soybeans, and wheat occurred primarily in the earlier part of the study period; per acre soil erosion has remained relatively constant for these crops in recent years.
  - o Total soil erosion has improved (decreased) for corn (-31%), cotton (-42%), potatoes (-42%), soybeans (-28%), and wheat (-57%) and increased for rice (+9%) (rice has historically had low levels of total soil erosion and increases are likely associated with increased acreage). However, improvements (decreases) in total soil erosion for corn and soybeans occurred primarily in the first half of the study period, with increases occurring in more recent years associated with increased production.
- **Irrigation Water Applied**
  - o Irrigation water applied per unit of production has improved (decreased) for all six crops: corn (-53%), cotton (-75%), potatoes (-38%), rice (-53%), soybeans (-42%), and wheat (-12%).
  - o Per acre irrigation water applied has improved (decreased) for corn (-28%), cotton (-46%), rice (-25%), and soybeans (-9%) and decreased slightly for potatoes (-2%); per acre irrigation water applied increased for wheat (+6%).
  - o Total irrigation water applied decreased for cotton (-35%), rice (-18%), and wheat (-12%) and increased for corn (+27%), potatoes (+31%), and soybeans (+271%).
- **Energy use**
  - o Energy use per unit of production has improved (decreased) for all six crops: corn (-44%), cotton (-31%), potatoes (-15%), rice (-38%), soybeans (-48%), and wheat (-12%).
  - o Per acre energy use improved (decreased) for corn (-6%), cotton (-2%), rice (-3%), and soybeans (-17%), and increased for potatoes (+33%) and wheat (+9%).
  - o Total energy use decreased for wheat (-26%), and increased for corn (+14%), cotton (+9%), potatoes (+11%), rice (+6%), and slightly for soybeans (+3%).

- **Greenhouse gas emissions**
  - Greenhouse gas emissions per unit of production have improved (decreased) for all six crops: corn (-36%), cotton (-22%), potatoes (-22%), rice (-38%), soybeans (-49%), and wheat (-2%).
  - Per acre greenhouse gas emissions improved (decreased) for rice (-4%) and soybeans (-18%), and increased for corn (+8%), cotton (+9%), potatoes (+23%), and wheat (+21%).
  - Total greenhouse gas emissions decreased for wheat (-17%), increased slightly for potatoes (+3%) and soybeans (+1%), and increased for corn (+31%), cotton (+20%), and rice (+5%).

3.2. Corn for Grain Summary of Results

Overview (Corn for Grain)

Over the study period (1980-2011), trends in U.S. corn production were as follows:

- Yield: Corn increased in total production (+101%) and yield (bushels per acre) (+64%).
- Resource efficiency (per bushel): Corn improved on all measures of resource "efficiency," with decreases in per bushel land use (-30%), soil erosion (-67%), irrigation water applied (-53%), energy use (-44%), and greenhouse gas emission (-36%).
- Resource use/impact per acre: Corn improved (decreased) per acre soil erosion (-43%), irrigation water applied (-28%), and energy use (-6%) and increased per acre greenhouse gas emissions (+8%). Improvements in per acre soil erosion occurred primarily in the first half of the study period; per acre soil erosion has remained relative constant since the late-1990s.
- Total resource use/impact: Corn improved (decreased) total soil erosion (-31%) and increased total land use (+21%), irrigation water applied (+27%), energy use (+14%), and greenhouse gas emissions (+31%). Improvements in total soil erosion occurred primarily in the first half of the study period, with more recent trends indicating a slight increase in total annual erosion.

Please note: all results are for corn for grain; corn for grain includes corn for all purposes other than forage; corn for grain includes grain for ethanol. A summary of trends for specific indicators are provided in **Figure 1.1** and **Table 1.1** and in the text below. **Figures 1.2 through 1.16** demonstrate linear trends over the full study period for total, per acre, and per unit of production resource use/impacts. Average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted below.

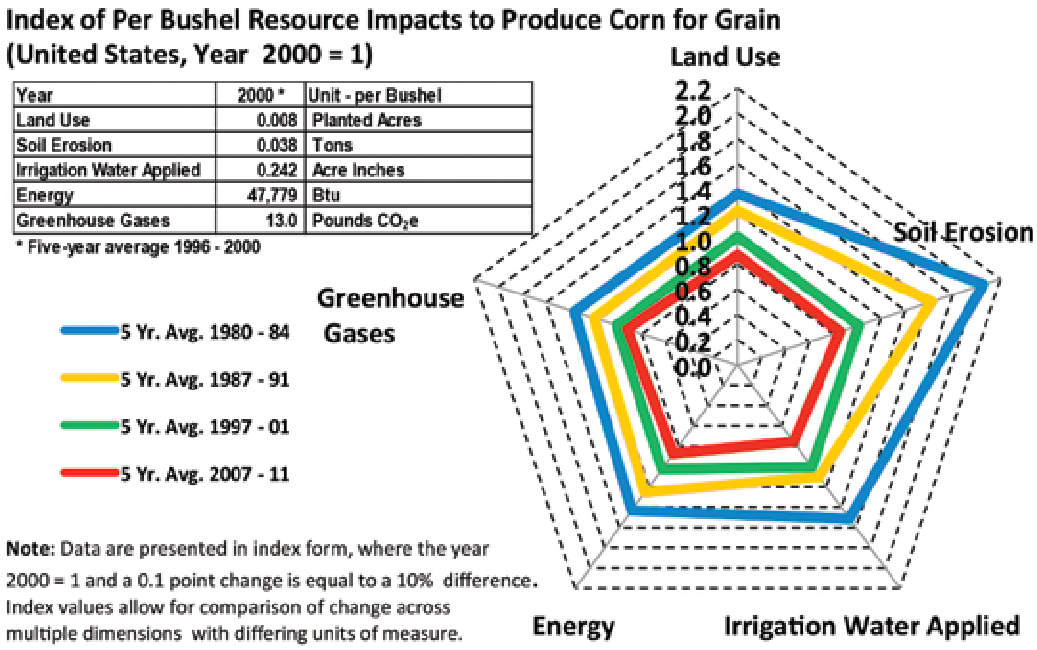


Figure 1.1 Index of Per Bushel Resource Impacts to Produce Corn for Grain, United States, 1980-2011

Table 1.1 Corn for Grain Summary of Results

Corn Summary of Results:
Trends in U.S. Production, Resource Use / Impact, 1980-2011

Resource Area	Indicator	Percent Change* 1980-2011		
		Trend Direction	Entire Period	Compound Annual
Crop Yield	Total Production	↑	101	2.3
	Bushels per Acre	↑	64	1.6
Land Use	Total Planted Acres	↑	21	0.6
	Acres per Bushel	↓	(30)	(1.1)
Soil Erosion	Total Tons	↓	(31)	(1.2)
	Tons per Acre	↓	(43)	(1.8)
	Tons per Bushel	↓	(67)	(3.5)
Irrigation Water Applied	Total Volume	↑	27	0.8
	Volume per Irrigated Acre	↓	(28)	(1.0)
	Volume per Bushel	↓	(53)	(2.4)
Energy Use	Total Btu	↑	14	0.4
	Btu per Acre	↓	(6)	(0.2)
	Btu per Bushel	↓	(44)	(1.9)
GHG Emissions (CO_2 Equivalents)	Total Pounds	↑	31	0.9
	Pounds per Acre	↑	8	0.2
	Pounds per Bushel	↓	(36)	(1.4)

*Percent change results are based on a least squares trends analyses from 1980 - 2011

Sources: Calculations are based on a number of data sources: 1. USDA, NASS, Census of Agriculture, Farm and Ranch Irrigation Survey, http://www.agcensus.usda.gov/Publications/index.php 2. USDA, Economic Research Service (ERS), Agricultural Resource Management Survey (ARMS) http://www.ers.usda.gov/Briefing/ARMS/Access.htm 3. USDA, National Resources Conservation Service (NRCS), National Resrouce Inventory (NRI) Reports http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri

Total Production and Yield (Corn for Grain)

Total production and yield for corn for grain increased over the study period. Total production of corn increased by 101 percent, or 2.3 percent compound annually; 12.4 billion bushels of corn were produced in 2011 compared with 6.64 billion bushels in 1980. The increase in production corresponded with a 21 percent increase in total planted acreage over the study period (see land use, below). Bushels per planted acre increased 64 percent over the study period, or 1.6 percent compound annually; average planted area yield in 2011 was 145 bushels per planted acre, compared to 89.1 bushels per planted acre in 1980. The yield per harvested acre in 2011 was 147 bushels. Both planted and harvested yields for corn for grain were below expectations in 2011 and lower than in previous years; adverse conditions, particularly caused by flooding along the Mississippi and Missouri Rivers, drove increased abandonment (impacting planted acre yields) as well as poorer yields on acres that were harvested.

Land Use (Corn for Grain)

Total planted acreage of corn for grain increased over the study period while land use per bushel decreased. Total planted acreage increased by 21 percent, or 0.6 percent compound annually; 85.8 million acres of corn for grain were planted in 2011 as compared to 74.5 million acres planted in 1980. The harvested acre area of corn for grain in 2011 was 84.0 million acres, reflecting 1.8 million acres of abandonment in that year. 2011 abandonment was larger than normal due to adverse conditions. Over the study period, the land use "efficiency" metric (planted acres per bushel) improved (decreased) by 30 percent, or 1.1 percent compound annually.

Please note: all numbers are based on estimated planted area of corn for grain (which does not include corn for silage or forage, but does include corn grain for ethanol); 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, 93.4 percent of corn harvested for all purposes was for grain.

See **Figures 1.2, 1.3 and 1.4** for more detail regarding the annual land use, production, and yield values

Soil Erosion (Corn for Grain)

Soil erosion for corn for grain improved for all measures. Total tons of soil erosion for corn decreased 31 percent over the study period, or 1.2 percent compound annually; total erosion was 563 million tons in 1980 and 416 million tons in 2011. In absolute terms (not relative to a tolerance rate or T), per acre soil erosion decreased 43 percent (1.8 percent compound annually), to 4.85 tons per acre in 2011 compared with 7.56 tons per acre in 1980. (Note: Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre). Tons per bushel decreased 67 percent (3.5 percent compound annually).

While the trend since 1980 shows significant improvement in total and per acre soil erosion, these improvements occurred primarily before the mid-1990s, likely attributable in large part to implementation of conservation plans, particularly on highly erodible lands. Since the late-1990s, per acre erosion for corn has remained relatively constant (near 5 tons per acre). From the mid-1990s until 2006, total soil erosion remained relatively constant, but has increased in more recent years; for example, total soil erosion was 346 million tons in 1995, 350 million tons in 2006, and 416 million tons in 2011.

Please note: Due to the nature of the NRI datasets used for this soil erosion analysis, soil erosion rates for corn for grain and corn for silage were assumed to be equal; however, considering differences in harvest practices for silage and grain, it is expected that, on average, erosion from corn silage would be higher than that from corn grain, all other things being equal. Consequently, absolute levels of soil erosion for corn for grain may be slightly overestimated in this report.

See **Figures 1.5, 1.6 and 1.7** for more detail regarding the annual soil erosion values

Irrigation Water Applied (Corn for Grain)

Over the study period, corn for grain decreased its volume per irrigated acre and volume per bushel and increased its total irrigation water applied. Volume per irrigated acre decreased 28 percent (1.0 percent compound annually). Volume per incremental bushel produced as a result of irrigation also improved (decreased) (53 percent, 2.4 percent compound annually). Average per acre water use (per irrigated acre) was 12.0 acre inches in 2011 compared with 16.8 acre inches in 1980. Per acre irrigation water applied decreased through the first half of the study period, increased after 1995, then decreased again in the early part of this century.

Total irrigation water applied for corn for grain increased 27 percent (0.8 compound annually) over the study period, from 120 million acre inches in 1980 compared with 144 million acre inches in 2011. This increase corresponds with a proportionate increase of irrigated acreage as compared to non-irrigated acreage for corn over time. For example, over the study period, there was an estimated 59 percent increase in total irrigated land acreage for corn for grain, as compared to the 21 percent increase in planted acreage of corn for grain reported in the land use section, above.

Please note: Due to the nature of the Ag Census Farm and Ranch Irrigation Survey datasets used for this irrigation analysis, it was assumed that the irrigation water applied rate for corn for grain and corn for silage are equal, although irrigated acres for corn for grain most likely increased more than irrigated acres of corn for silage.

See **Figures 1.8, 1.9, and 1.10** for more detail regarding the annual irrigation water applied values.

Energy Use (Corn for Grain)

Over the study period, energy use per acre and per bushel decreased while total energy use increased for corn for grain. Energy use per acre decreased by 6 percent (0.2 percent compound annually); energy use was 6.3 million Btu per acre in 1980 compared with 6.1 million Btu per acre in 2011. Energy use per bushel of corn for grain production improved (decreased) 44 percent (1.9 percent compound annually) over the study period; energy use was 70.9 thousand Btu per bushel in 1980 and 42.1 thousand Btu per bushel in 2011. Total energy use for corn production increased an average of 14 percent (0.4 percent compound annually); total energy use was 471 trillion Btu in 1980 and 523 trillion Btu in 2011.

Decreases in energy use per acre are likely attributable to decreases in tillage energy over the full study period. Efficiency gains may be understated because our study does not capture efficiency gains from larger equipment use over time. Decreases in nitrogen application rates per acre were seen up to the mid-1990s, after which time application rates began to increase. Improvements in per bushel energy use are impacted by these factors but are largely driven by yield improvements.

See **Figures 1.11, 1.12, and 1.13** for more detail regarding the annual energy use values.

Greenhouse Gas Emissions (Corn for Grain)

Over the study period, greenhouse gas emissions per bushel decreased while per acre and total emissions increased for corn for grain. Greenhouse gas emissions per bushel of corn for grain improved (decreased) 36 percent (1.4 percent compound annually) over the study period, from approximately 18.5 pounds CO2e per bushel in 1980 to approximately 12.7 pounds CO2e per bushel in 2011. Emissions per acre increased 8 percent (0.2 percent compound annually), from approximately 1,650 pounds CO2e per acre in 1980 to approximately 1,836 pounds CO2e per acre in 2011. Total greenhouse gas emissions for corn for grain production increased 31 percent (0.9 percent compound annually), from 123 billion pounds CO2e in 1980 to 158 billion pounds CO2e in 2011; this increase is largely attributable to increased planted acreage for corn.

See **figures 1.14, 1.15, and 1.16** for more detail regarding the annual greenhouse gas emissions values.

Please note, in the following graphs, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

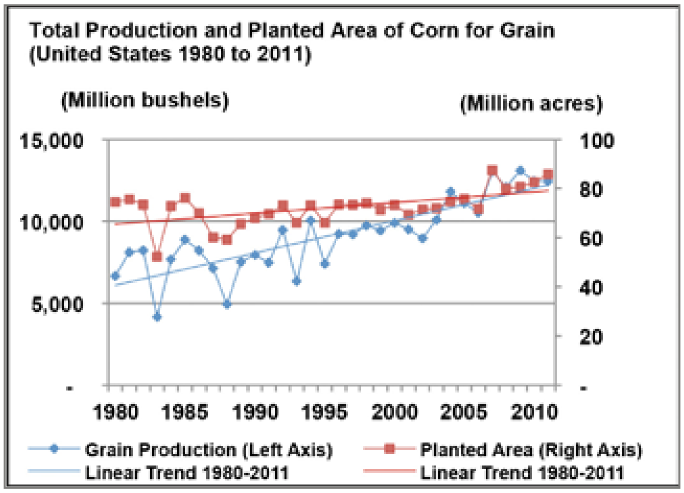


Figure 1.2 Total Production and Planted Area of Corn for Grain, U.S. 1980 to 2011

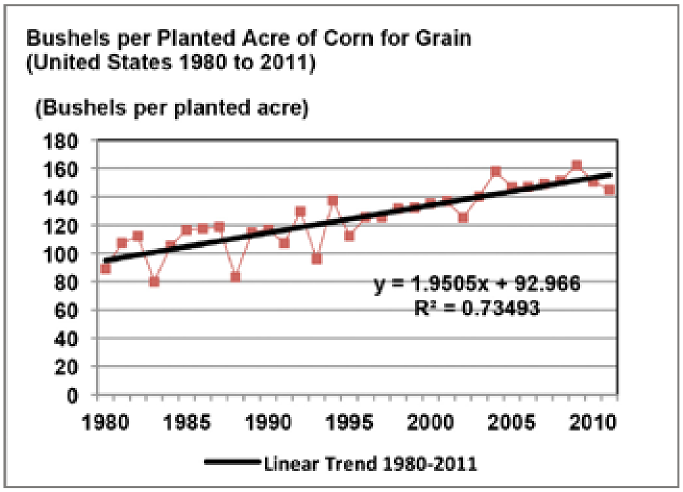


Figure 1.3 Bushels per Planted Acre of Corn for Grain, U.S. 1980 to 2011

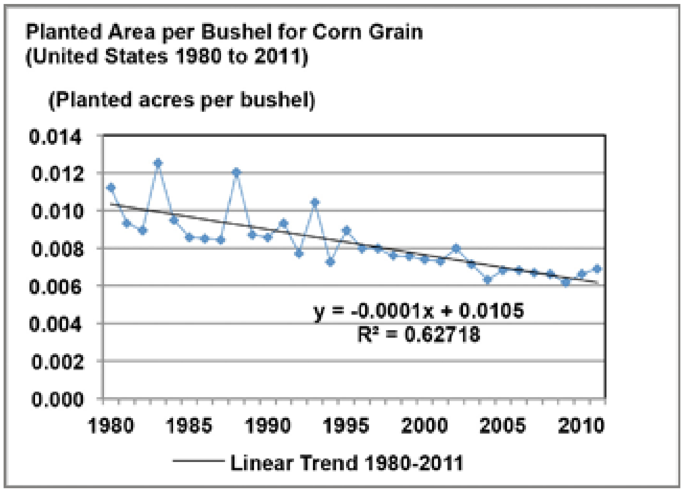


Figure 1.4 Planted Area per Bushel of Corn for Grain, U.S. 1980 to 2011

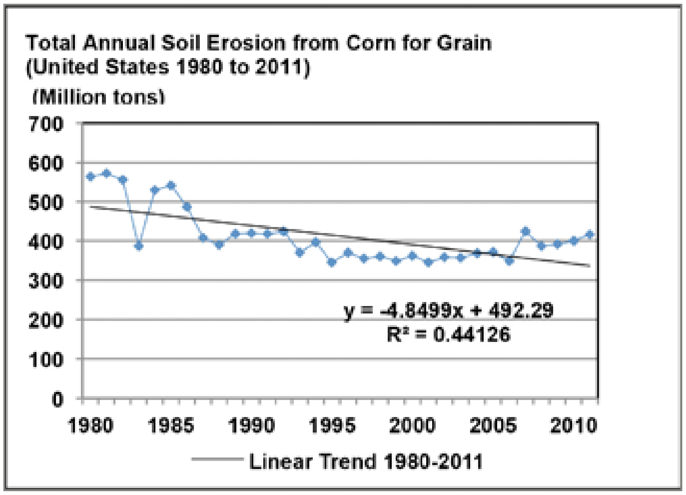


Figure 1.5 Total Annual Soil Erosion from Corn for Grain, U.S. 1980 to 2011

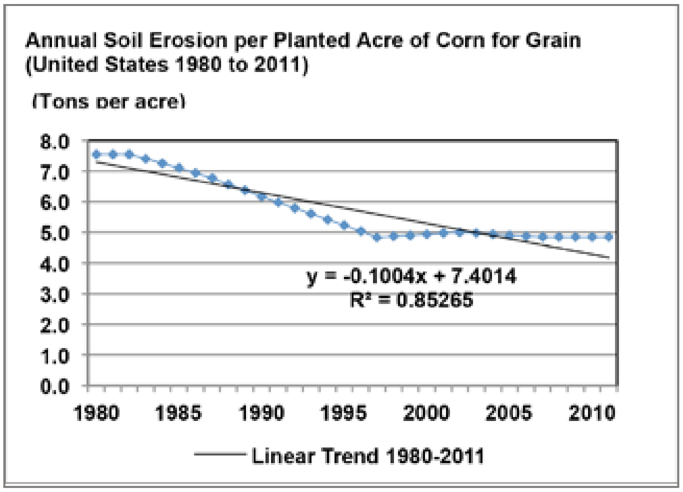


Figure 1.6 Annual Soil Erosion per Planted Acre of Corn for Grain, U.S. 1980 to 2011

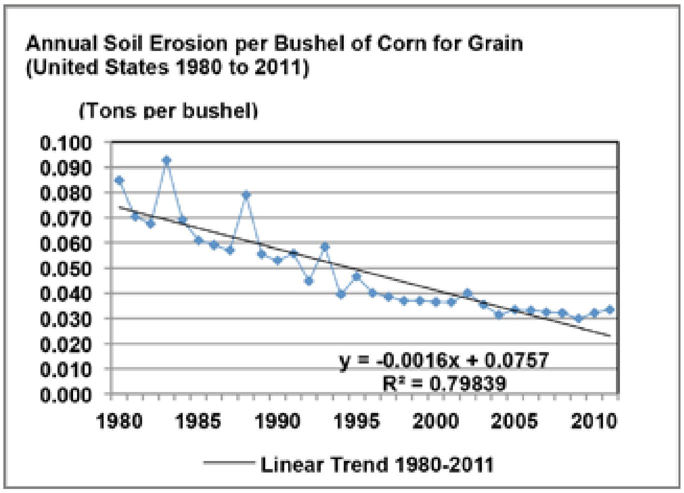


Figure 1.7 Annual Soil Erosion per Bushel of Corn for Grain, U.S. 1980 to 2011

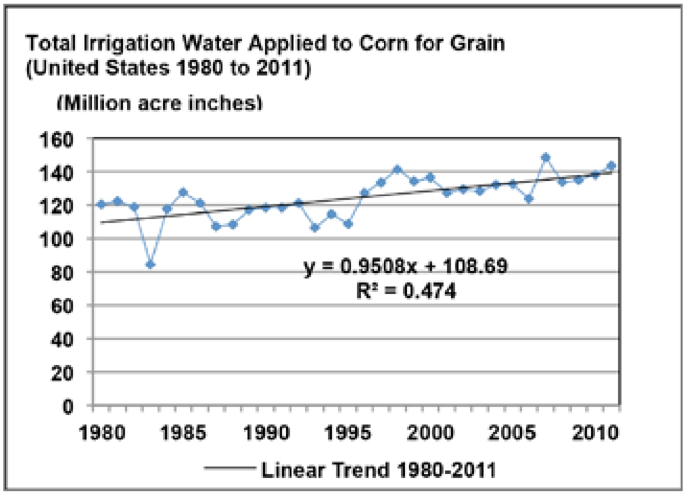


Figure 1.8 Total Irrigation Water Applied to Corn for Grain, U.S. 1980 to 2011

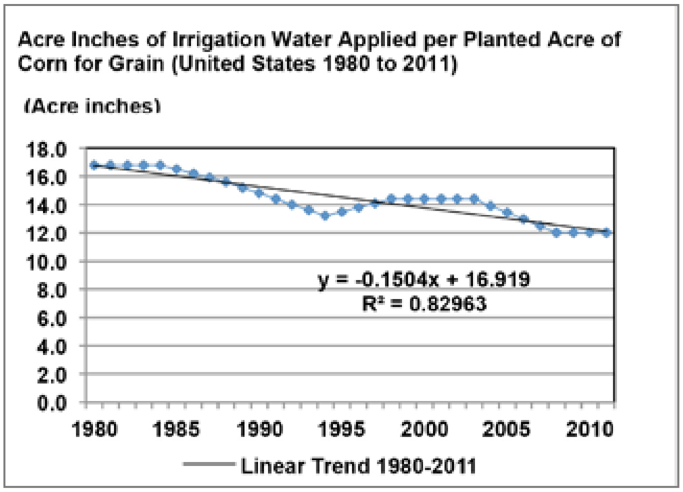


Figure 1.9 Acre Inches of Irrigation Water Applied per Planted Acre of Corn for Grain, U.S. 1980 to 2011

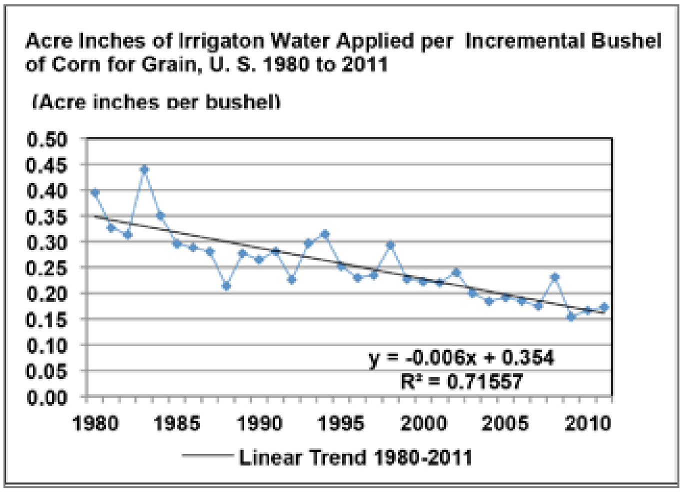


Figure 1.10 Acre Inches of Irrigation Water Applied per Incremental Bushel of Corn for Grain, U.S. 1980 to 2011

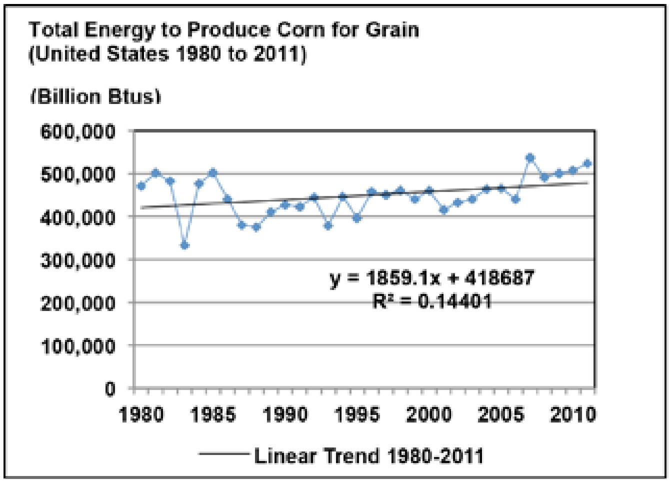


Figure 1.11 Total Energy to Produce Corn for Grain, U.S. 1980 to 2011

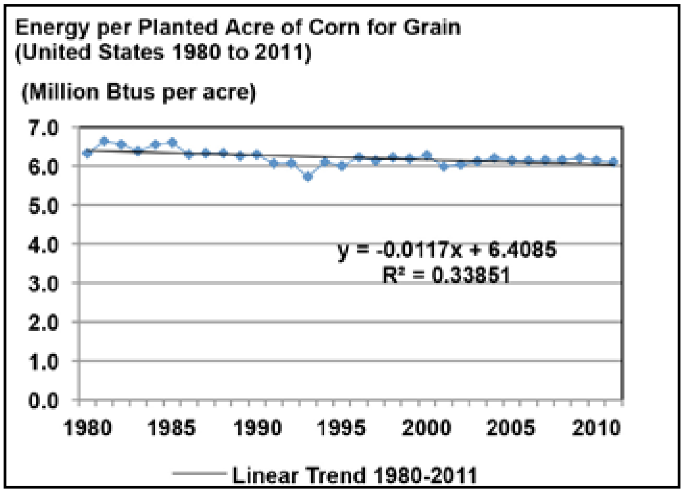


Figure 1.12 Energy per Planted Acre of Corn for Grain, U.S. 1980 to 2011

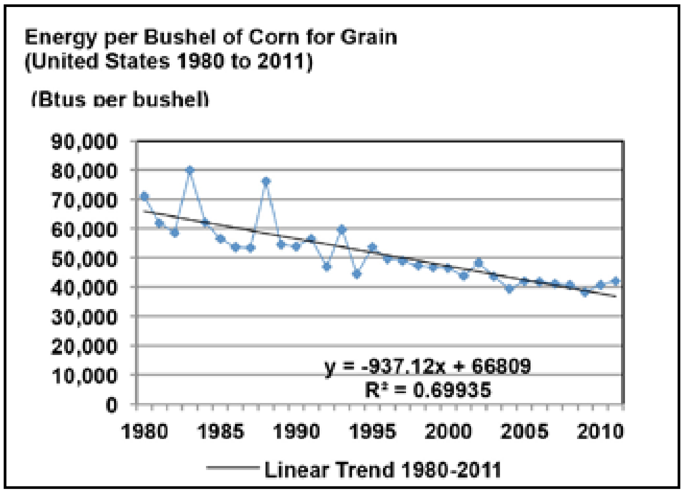


Figure 1.13 Energy per Bushel of Corn for Grain, U.S. 1980 to 2011

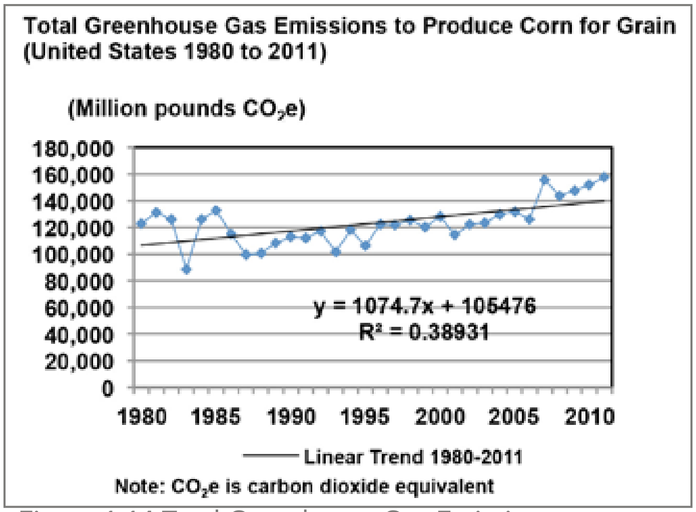


Figure 1.14 Total Greenhouse Gas Emissions to Produce Corn for Grain, U.S. 1980 to 2011

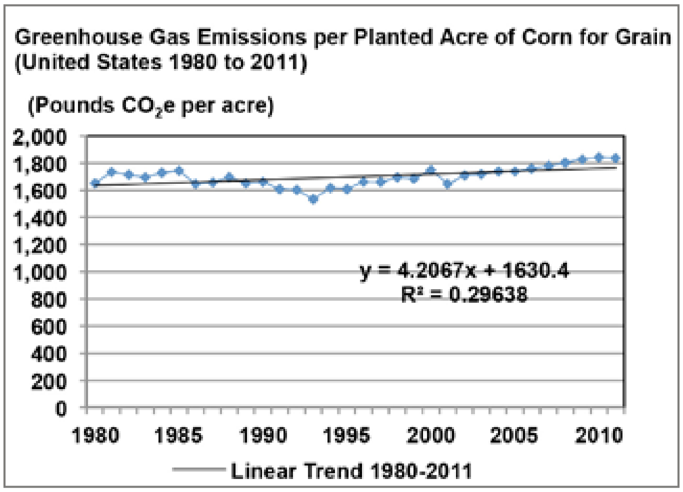


Figure 1.15 Greenhouse Gas Emissions per Planted Acre of Corn for Grain, U.S. 1980 to 2011

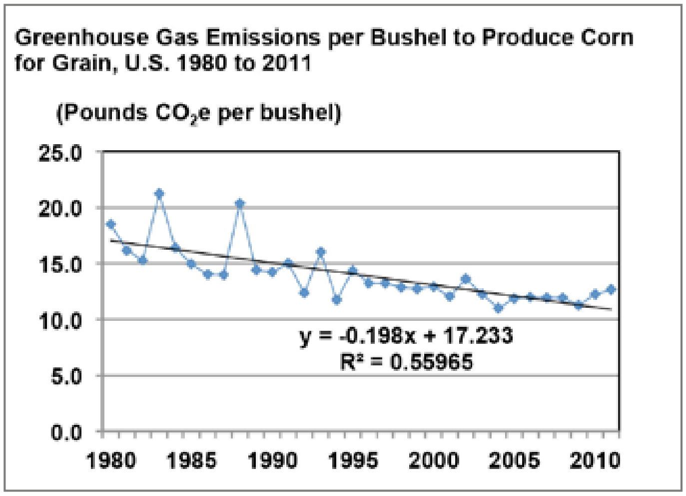


Figure 1.16 Greenhouse Gas Emissions per Bushel of Corn for Grain, U.S. 1980 to 2011

3.3. Cotton Summary of Results

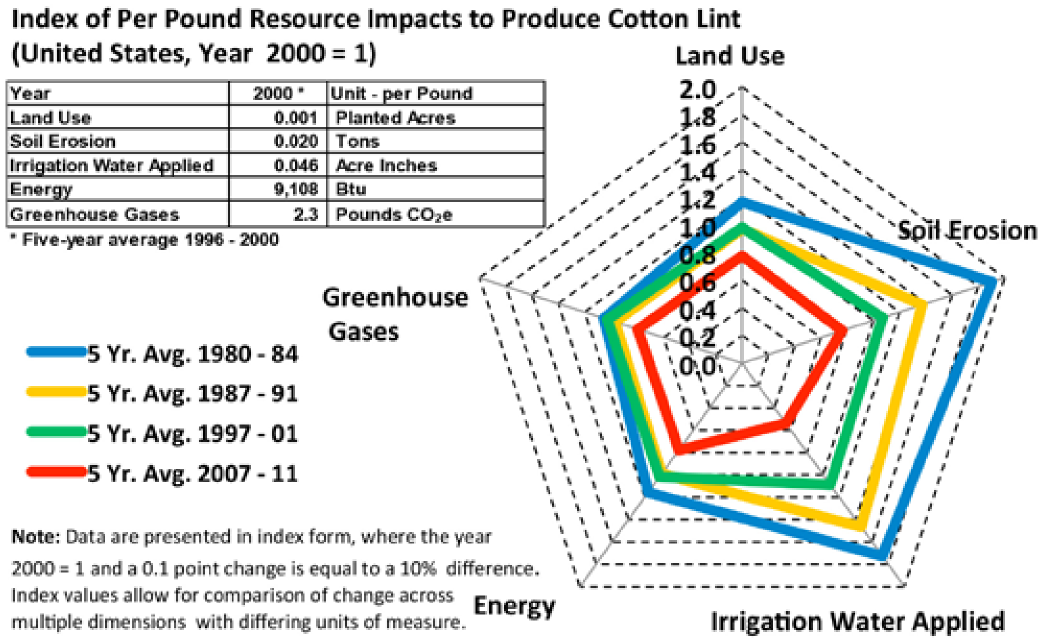
Overview

Over the study period (1980-2011), trends in U.S. cotton production were as follows:

- Yield: Cotton increased in total production (+55%) and yield (pounds lint per planted acre) (+43%).
- Resource efficiency (per pound of lint): Cotton improved on all measures of resource "efficiency," with decreases in per pound lint land use (-30%), soil erosion (-68%), irrigation water applied (-75%), energy use (-31%), and greenhouse gas emissions (-22%).
- Resource use/impact per acre: Cotton improved (decreased) per acre soil erosion (-50%) and irrigation water applied (-46%); per acre energy use decreased slightly (-2%) and greenhouse gas emissions per acre increased (9%) The most significant improvement in per acre soil erosion occurred in the first half of the study period.
- Total resource use/impact: Cotton improved (decreased) total soil erosion (-42%) and irrigation water applied (-35%); cotton increased total land use (+11%), energy use (+9%) and greenhouse gas emissions (20%).

Please note: cotton resource use/impact for soil, energy, irrigation water applied and greenhouse gas emissions are allocated between seed and lint using an economic allocation method, with 83 percent of use and resource impact values being attributed to lint and 17 percent to seed based on 2005-2009 economic data (land use acreage is not allocated). Values for cotton lint may be converted to values representing that required to produce both economic yield components, lint and seed, by multiplying lint values by 1.17.

Summary trends for specific indicators are provided in **Figure 1.17** and **Table 1.2** and in the text below. **Figures 1.18 through 1.32** demonstrate linear trends over the full study period for total, per acre, and per unit of production resource use/impacts. Average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted below.



Year	2000 *	Unit - per Pound
Land Use	0.001	Planted Acres
Soil Erosion	0.020	Tons
Irrigation Water Applied	0.046	Acre Inches
Energy	9,108	Btu
Greenhouse Gases	2.3	Pounds CO_2e

Figure 1.2 Index of Per Pound Resource Impacts to Produce Cotton Lint,United States, 1980-2011

Table 1.2 Cotton Lint Summary of Results

Cotton Summary of Results:
Trends in U.S. Production, Resource Use / Impact, 1980-2011

Resource Area	Indicator	Percent Change* 1980-2011		
		Trend Direction	Entire Period	Compound Annual
Crop Yield	Total Production	↑	**55**	**1.4**
	Pounds per Acre	↑	**43**	**1.2**
Land Use	Total Planted Acres	↑	**11**	**0.3**
	Acres per Pound	↓	**(30)**	**(1.2)**
Soil Erosion	Total Tons	↓	**(42)**	**(1.7)**
	Tons per Acre	↓	**(50)**	**(2.2)**
	Tons per Pound	↓	**(68)**	**(3.6)**
Irrigated Water Applied	Total Volume	↓	**(35)**	**(1.4)**
	Volume per Irrigated Acre	↓	**(46)**	**(2.0)**
	Volume per Pound	↓	**(75)**	**(4.4)**
Energy Use	Total Btu	↑	**9**	**0.3**
	Btu per Acre	↓	**(2)**	**(0.1)**
	Btu per Pound	↓	**(31)**	**(1.2)**
GHG Emissions (CO_2 Equivalents)	Total Pounds	↑	**20**	**0.6**
	Pounds per Acre	↑	**9**	**0.3**
	Pounds per Pound	↓	**(22)**	**(0.8)**

*Percent change results are based on a least squares trends analyses from 1980 - 2011

Sources: Calculations are based on a number of data sources: 1. USDA, NASS, Census of Agriculture, Farm and Ranch Irrigation Survey, http://www.agcensus.usda.gov/Publications/index.php 2. USDA, Economic Research Service (ERS), Agricultural Resource Management Survey (ARMS) http://www.ers.usda.gov/Briefing/ARMS/Access.htm 3. USDA, National Resources Conservation Service (NRCS), National Resrouce Inventory (NRI) Reports http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri

Total Production and Yield (Cotton Lint)

Over the study period, total production and yield for cotton lint increased. Total production of cotton lint increased by 55 percent, or 1.4 percent compound annually; 7.53 billion pounds of cotton lint were produced in 2011 compared with 5.34 billion pounds in 1980. Yield (pounds lint per acre) increased 43 percent over the study period, or 1.2 percent compound annually; average planted acre yield in 2011 was 616 pounds per planted acre as compared with 443 pounds per planted acre in 1980. The yield per harvested acre in 2011 was 790 pounds. The gap between planted and harvested acre yields is driven by abandonment, which in the case of cotton can be highly variable.

Land Use (Cotton Lint)

Over the study period, total land use increased and land per pound lint decreased. Total planted acreage of cotton increased by 11 percent, or 0.3 percent compound annually; however, there was significant variability in planted acreage over the study period: 12.2 million acres of cotton were planted in 2011 compared with lows of 6.58 million and 7.59 million planted acres in 1983 and 2009, respectively, and a high of 14.1 million acres in 1995. The harvested acre area of cotton in 2011 was 9.5 million acres, reflecting 2.7 million acres of abandonment in that year. 2011 abandonment was dramatically larger than normal due to adverse conditions, particularly in Texas. The land use "efficiency" metric (acres per pound lint) improved (decreased) by 30 percent, or 1.2 percent compound annually.

See **Figures 1.18, 1.19, and 1.20** for more detail regarding the annual land use, production, and yield values.

Soil Erosion (Cotton Lint)

Soil erosion for cotton improved for all measures. Total tons of soil erosion for cotton decreased 42 percent over the study period, or 1.7 percent compound annually; total soil erosion was 151 million tons in 2011 compared with 249 million tons in 1980. In absolute terms (not relative to a tolerance rate or T), per acre soil erosion improved (decreased) 50 percent (2.2 percent compound annually); per acre soil erosion was 10.3 tons in 2011 compared with 17.2 tons per acre in 1980. (Note: Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre). While the trend since 1980 shows significant improvement per acre soil erosion, the largest improvement occurred in the first half of the study period, and trends in per acre soil erosion have remained relatively constant since the early 2000's. Tons per pound of lint decreased 68 percent (3.6 percent compound annually).

See **Figures 1.21, 1.22, and 1.23** for more detail regarding the annual soil erosion values.

Irrigation Water Applied (Cotton Lint)

Irrigation water applied for cotton improved on all measures. Over the study period, total irrigation water applied for cotton decreased 35 percent (1.4 percent compound annually); total water use was 95.5 million acre inches in 1980 and 62.9 million acre inches in 2011. Cotton decreased its volume per irrigated acre (46 percent, 2.0 percent compound annually), from 20.9 acre inches per acre in 1980 to 13.0 acre inches per acre in 2011. Volume per incremental pound of lint produced as a result of irrigation also improved (decreased) (75 percent, 4.4 percent compound annually).

The proportion of irrigated cotton acreage (as compared to non-irrigated acreage) has remained relatively constant over the study period, at approximately 32 percent; total irrigated acreage has thus increased at a rate generally corresponding with overall trends in total land use for cotton use. On a per acre and per pound basis, irrigation technology has largely driven improvements in irrigated water use for cotton.

See **Figures 1.24, 1.25., and 1.26** for more detail regarding the annual irrigation water applied values.

Energy Use (Cotton Lint)

Over the study period, energy use decreased per acre and per bushel and total energy use increased for cotton lint. Energy use per acre decreased slightly by 2 percent (0.1 percent compound annually); energy use per acre was approximately 4.6 million Btu in 2011 compared with 4.7 million Btu in 1980. Energy use per pound of cotton lint produced improved (decreased) 31 percent (1.2 percent compound annually) over the study period; energy use per pound was 9,000 Btu in 2011 compared to 12,900 in 1980. Improvements in energy use efficiency per pound are driven in part by improvements in irrigation water efficiency resulting in decreased pumping energy.

Total energy use for cotton lint production increased 9 percent (0.3 percent compound annually), although the trend for total energy use varies considerably by year, with lower levels in the 1980s, followed by higher levels throughout the 1990s and early 2000s, and a decrease in the latter part of the study period that corresponds with a decrease in total planted acres and production. Total energy use for cotton lint was approximately 67.5 trillion Btu in 2011, compared to lows of 38.7 trillion Btu in 1983 and 44.0 trillion Btu in 2008, and a high of 86.8 trillion Btu in 1995.

See **Figures 1.27, 1.28, and 1.29** for more detail regarding the annual energy use values.

Greenhouse Gas Emissions (Cotton Lint)

Over the study period, greenhouse gas emissions per pound decreased and emissions per acre and total emissions both increased for cotton lint. Greenhouse gas emissions per pound of cotton lint improved (decreased) 22 percent (0.8 percent compound annually) over the study period; emissions were approximately 2.1 pounds CO2e per pound lint in 1980 and 1.9 pounds CO2e per pound lint in 2011. 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.

Emissions per acre increased 9 percent over the study period, or 0.3 percent compound annually; however the last several years have seen emissions falling below the trend line, with emissions hovering near 1,000 pounds CO2e per acre throughout much of the study period but declining to 1,077 pounds CO2e per acre in 2011.

Total greenhouse gas emissions for cotton production increased 20 percent (0.6 percent compound annually), from approximately 11.2 billion pounds CO2e in 1980 to approximately 14.6 billion pounds CO2e in 2011. Although the average trend for total emissions for the full study period shows an increase, a decrease in the latter part of the study period (2007-2010) corresponds with the decrease in total planted acres and production.

See **Figures 1.30, 1.31, and 1.32** for more detail regarding the annual energy use values.

Please note, in the following graphs, the regression equations and R2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend. r bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that

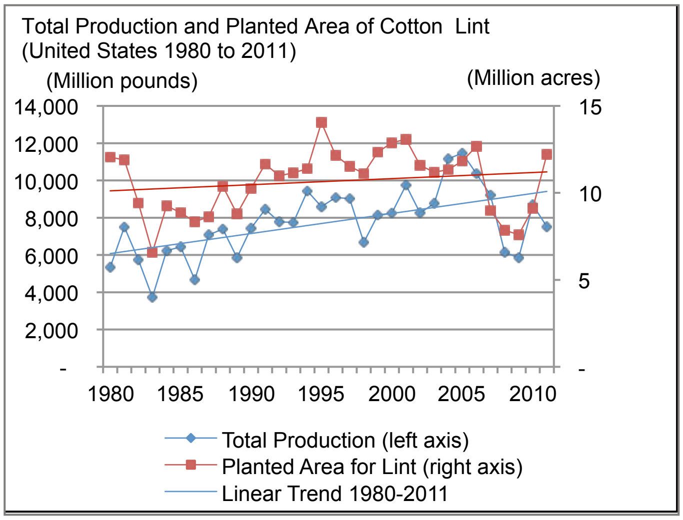


Figure 1.18 Total Production and Planted Area of Cotton Lint, U.S. 1980 to 2011

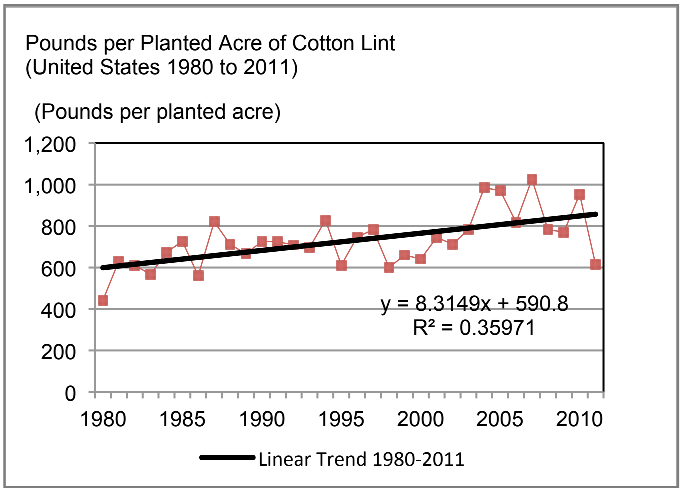


Figure 1.19 Pounds per Planted Acre of Cotton Lint, U.S. 1980 to 2011

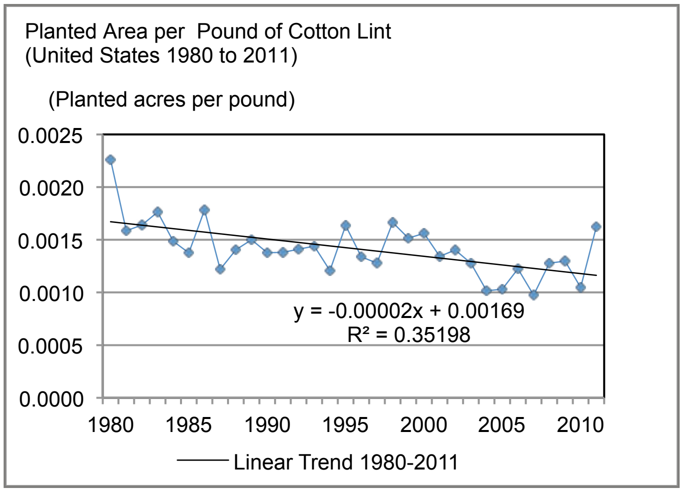


Figure 1.20 Planted Area per Pound of Cotton Lint, U.S. 1980 to 2011

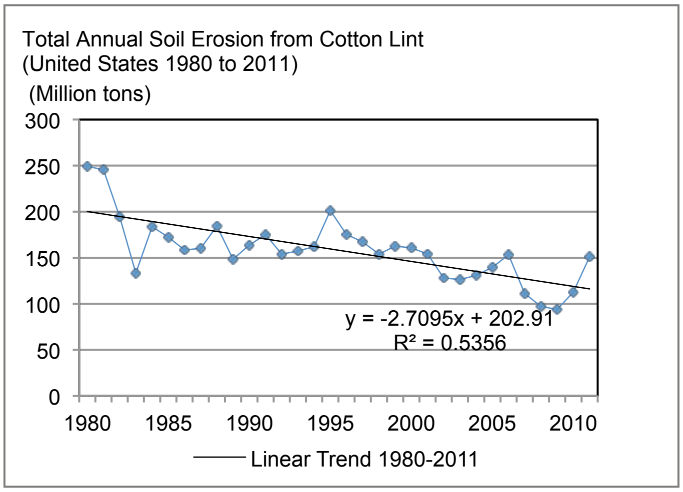


Figure 1.21Total Annual Soil Erosion from Cotton Lint, U.S. 1980 to 2011

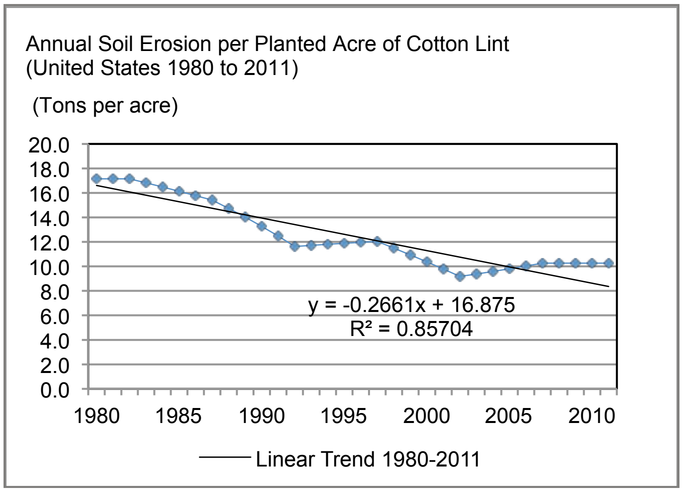


Figure 1.22 Annual Soil Erosion per Planted Acre of Cotton Lint, U.S. 1980 to 2011

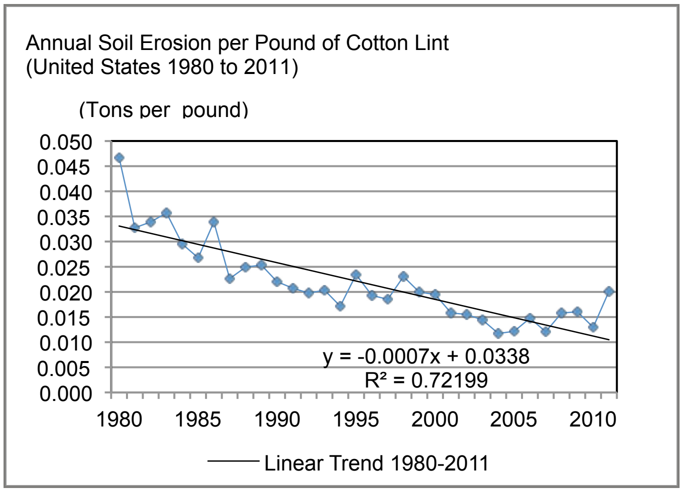
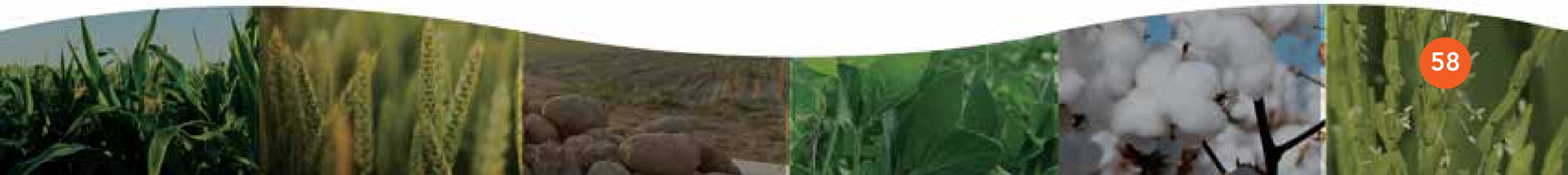


Figure 1.23 Annual Soil Erosion per Pound of Cotton Lint, U.S. 1980 to 2011



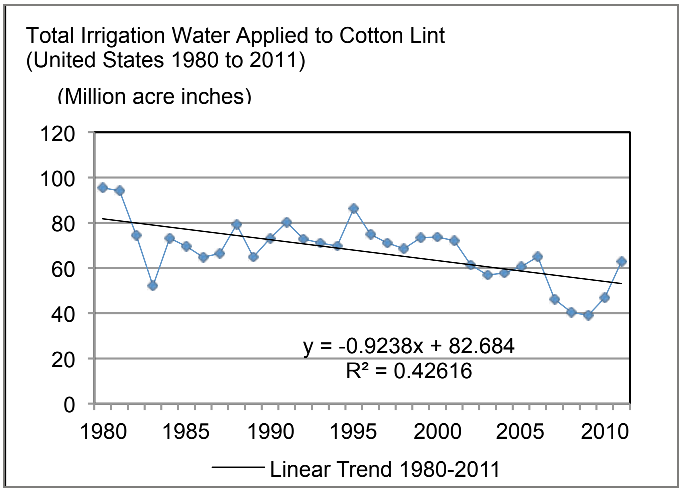


Figure 1.24 Total Irrigation Water Applied to Cotton Lint, U.S. 1980 to 2011

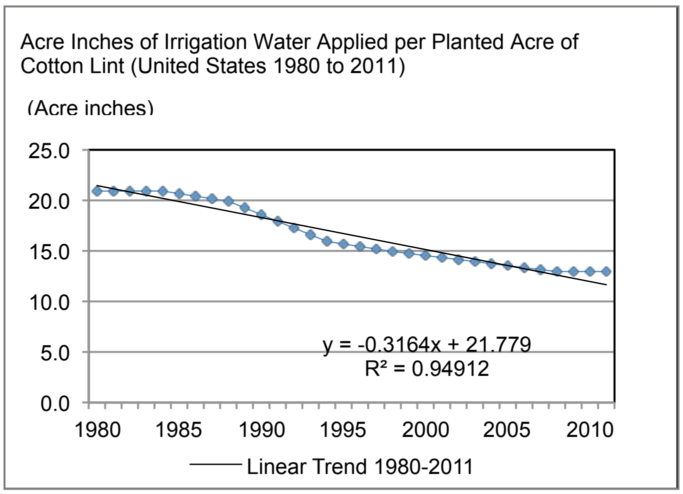


Figure 1.25 Acre Inches of Irrigation Water Applied per Planted Acre of Cotton Lint, U.S. 1980 to 2011

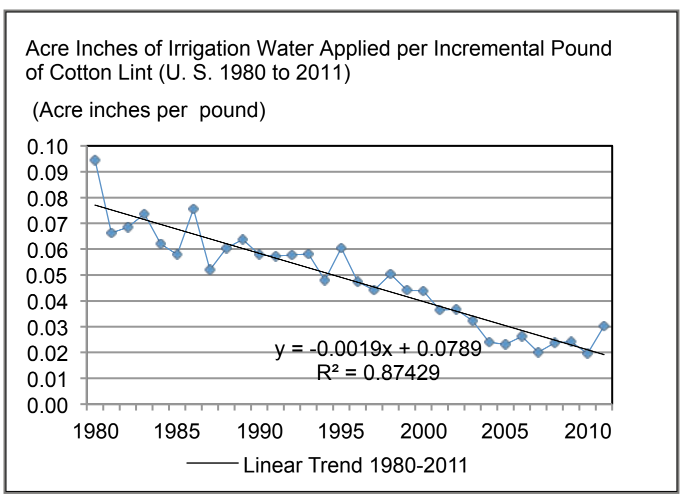


Figure 1.26 Acre Inches of Irrigation Water Applied per Incremental Pound of Cotton Lint, U.S. 1980 to 2011

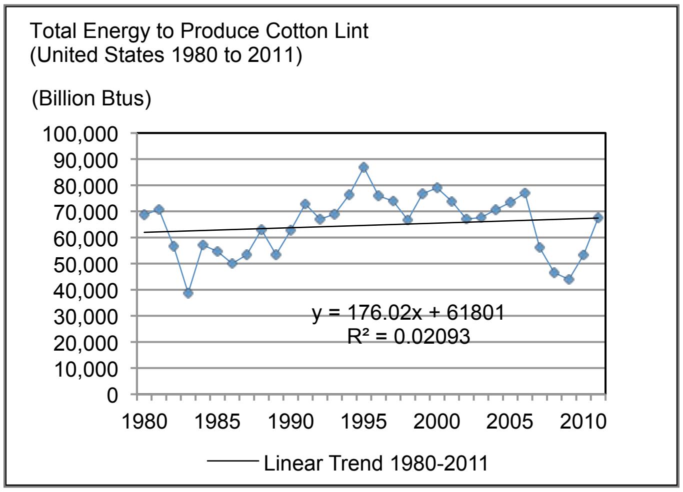


Figure 1.27 Total Energy to Produce Cotton Lint, U.S. 1980 to 2011

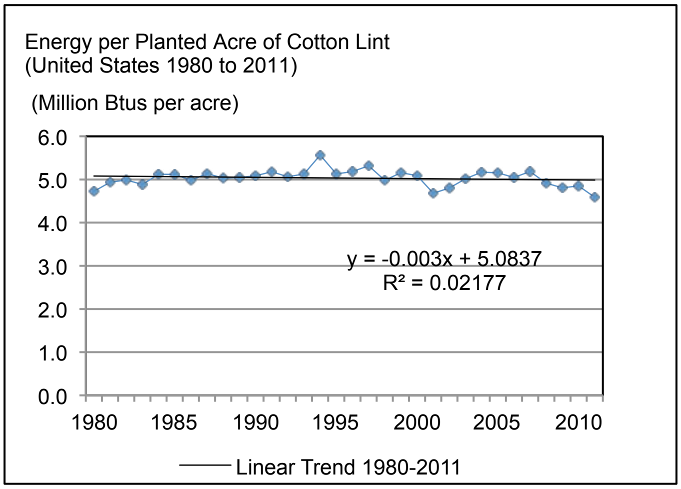


Figure 1.28 Energy per Planted Acre to Produce Cotton Lint, U.S. 1980 to 2011

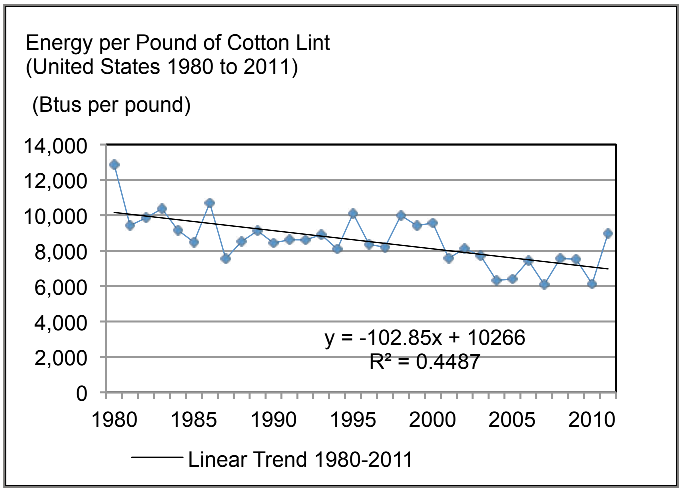


Figure 1.29 Energy per Pound of Cotton Lint, U.S. 1980 to 2011

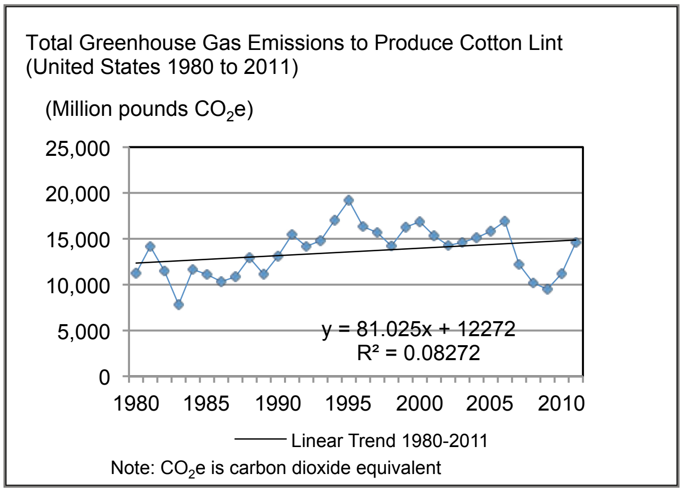


Figure 1.30 Total Greenhouse Gas Emissions to Produce Cotton Lint, U.S. 1980 to 2011

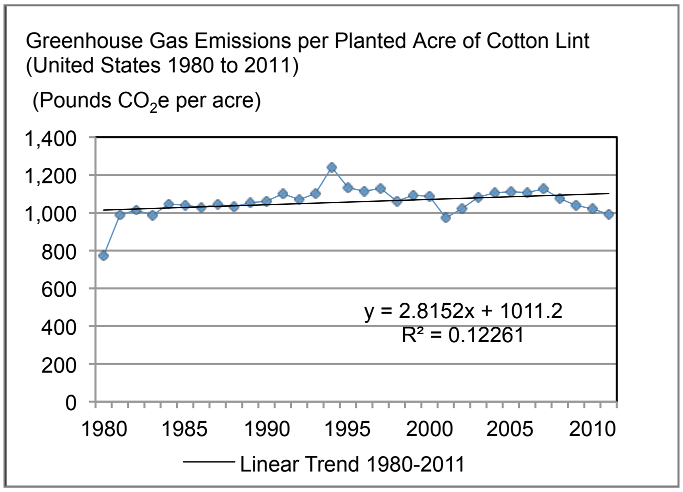


Figure 1.31 Greenhouse Gas Emissions per Planted Acre of Cotton Lint, U.S. 1980 to 2011

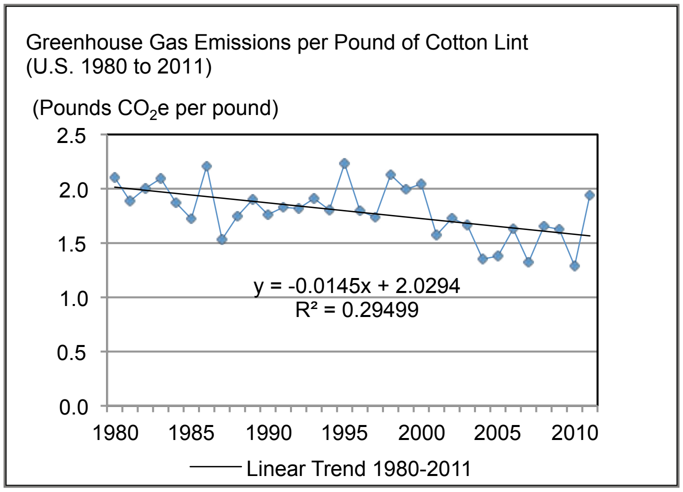


Figure 1.32 Greenhouse Gas Emissions per Pound of Cotton Lint, U.S. 1980 to 2011

3.4. Potatoes Summary of Results

Overview

Over the study period (1980-2011), trends in U.S. potato production were as follows:

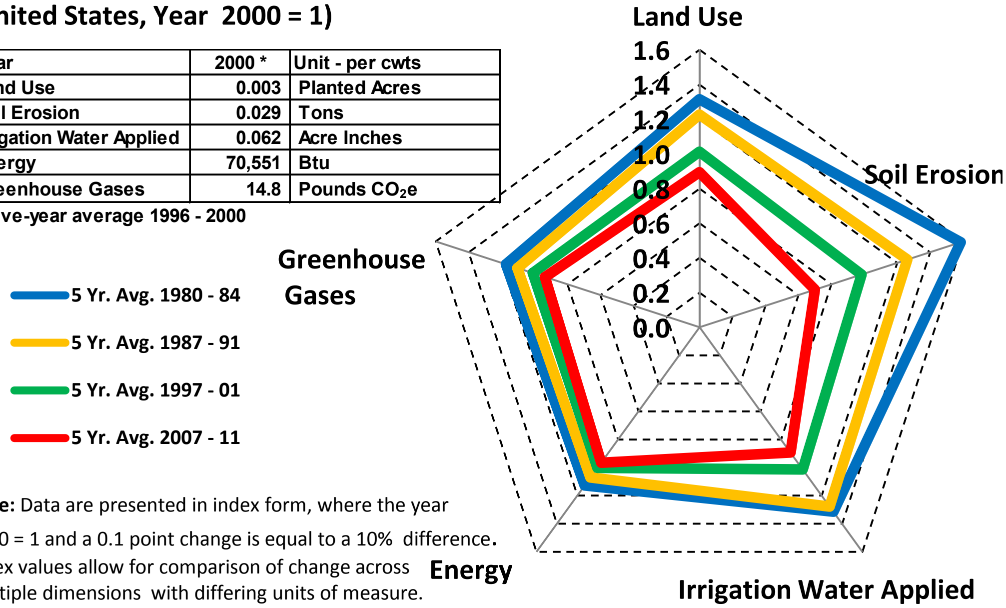
- **Yield:** Total potato production increased (+30%) and yield (cwts per planted acre) increased (+58%).
- **Resource efficiency (per cwt):** Potatoes improved on all measures of resource "efficiency," with decreases in land use (-37%), soil erosion (-60%), irrigated water use (-38%), energy use (-15%), and greenhouse gas emissions per cwt (-22%).
- **Resource use/impact per acre:** Potatoes improved (decreased) per acre soil erosion (-34%); irrigation water applied per acre remained nearly constant (-2%) while per acre energy use (+33%) and greenhouse gas emissions increased (+23%).
- **Total resource use/impact:** Potatoes improved (decreased) total soil erosion (-42%); total land use decreased (-15%), total greenhouse gas emissions increased slightly (+3%), and potatoes increased total irrigation water applied (+31%) and energy use (+11%).

For potatoes, the end point of this analysis is not point-of-sale but rather on-farm storage for 120 days. Due to the variability in on-farm storage length (ranging from no storage to as much as 10 months), this analysis assumes an average storage period of 120 days. Summary trends for specific indicators are provided in **Figure 1.33** and **Table 1.3** and in the text below. **Figures 1.34 through 1.48** demonstrate linear trends over the full study period for total, per acre, and per unit of production resource use/impacts. Average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted below.

Index of Per cwt Resource Impacts to Produce Potatoes (United States, Year 2000 = 1)

Year	2000 *	Unit - per cwts
Land Use	0.003	Planted Acres
Soil Erosion	0.029	Tons
Irrigation Water Applied	0.062	Acre Inches
Energy	70,551	Btu
Greenhouse Gases	14.8	Pounds CO_2e

* Five-year average 1996 - 2000



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

Figure 1.33 Index of Per cwt Resource Impacts to Produce Potatoes, United States, 1980-2011

Table 1.3 Potatoes Summary of Results

Potatoes Summary of Results: Trends in U.S. Production, Resource Use / Impact, 1980-2011				
Resource Area	Indicator	Percent Change* 1980-2011		
		Trend Direction	Entire Period	Compound Annual
Crop Yield	Total Production	↑	30	0.8
	Cwt per Acre	↑	58	1.5
Land Use	Total Planted Acres	↓	(15)	(0.5)
	Acres per cwt	↓	(37)	(1.5)
Soil Erosion	Total Tons	↓	(42)	(1.8)
	Tons per Acre	↓	(34)	(1.3)
	Tons per cwt	↓	(60)	(2.9)
Irrigation Water Applied	Total Volume	↑	31	0.9
	Volume per Irrigated Acre	↓	(2)	(0.1)
	Volume per cwt	↓	(38)	(1.6)
Energy Use	Total Btu	↑	11	0.3
	Btu per Acre	↑	33	0.9
	Btu per cwt	↓	(15)	(0.5)
GHG Emissions (CO_2 Equivalents)	Total Pounds	↑	3	0.1
	Pounds per Acre	↑	23	0.7
	Pounds per cwt	↓	(22)	(0.8)

*Percent change results are based on a least squares trends analyses from 1980 - 2011

Sources: Calculations are based on a number of data sources, including: 1. USDA, NASS, Census of Agriculture, Farm and Ranch Irrigation Survey, http://www.agcensus.usda.gov/Publications/index.php; 2. USDA, Economic Research Service (ERS), Agricultural Resource Management Survey (ARMS) http://www.ers.usda.gov/Briefing/ARMS/Access.htm; 3. USDA, National Resources Conservation Service (NRCS), National Resource Inventory (NRI) Reports http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri

Total Production and Yield (Potatoes)

Over the study period, total production and yield for potatoes both increased. Total production of potatoes increased over the study period by 30 percent, or 0.8 percent compound annually; 417 million cwt of potatoes were produced in 2011 as compared with 304 million cwt in 1980. Yield (cwt per planted acre) increased 58 percent over the study period, or 1.5 percent compound annually; average yield in 2011 was 380 cwt per planted acre as compared with 259 cwt per planted acre in 1980. The yield per harvested acre in 2011 was 397 cwt per harvested acre.

Two primary drivers in increased yield and increased production, despite decreased planted acreage (see below), have been increased irrigation and shifts in geographic patterns of potato growth toward higher producing areas.

Land Use (Potatoes)

Total land use and land use per cwt both decreased for potatoes over the study period. Total planted acreage of potatoes decreased over the study period by an average of 15 percent, or 0.5 percent compound annually; 1.03 million acres of potatoes were planted in 2011, as compared with 1.18 million acres in 1980. The harvested acre area of potatoes in 2011 was also 1.1 million acres; abandonment for potatoes is limited. Total land use and total production increased slightly through the middle of study period and then decreased more recently.

Over the study period, the land use "efficiency" metric (acres per cwt) improved (decreased) by 37 percent, or 1.5 percent compound annually.

See **Figures 1.34, 1.35, and 1.36** for more detail regarding the annual land use, production, and yield values.

Soil Erosion (Potatoes)

Soil erosion for cotton improved for all measures. Total tons of soil erosion for cotton decreased 42 percent over the study period, or 1.7 percent compound annually; total soil erosion was 151 million tons in 2011 compared with 249 million tons in 1980. In absolute terms (not relative to a tolerance rate or T), per acre soil erosion improved (decreased) 50 percent (2.2 percent compound annually); per acre soil erosion was 10.3 tons in 2011 compared with 17.2 tons per acre in 1980. (Note: Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre). While the trend since 1980 shows significant improvement per acre soil erosion, the largest improvement occurred in the first half of the study period, and trends in per acre soil erosion have remained relatively constant since the early 2000's. Tons per pound of lint decreased 68 percent (3.6 percent compound annually).

Decreases in total soil erosion for potatoes, particularly in more recent years, are driven in part by a decrease in total planted acreage. However, decreases in per acre erosion and erosion per cwt have also been realized, driven in part by use of cover crops as well as less intensive tillage programs (a reduction in the number of tillage passes). See **Figures 1.37, 1.38, and 1.39** for more detail regarding the annual soil erosion values.

Irrigation Water Applied (Potatoes)

Over the study period, potatoes improved irrigation water per applied cwt, slightly improved irrigation water applied per acre, and increased total irrigation water applied. Potatoes improved (decreased) irrigated volume per cwt by 38 percent, or 1.6 percent compound annually. Please note: because of data availability as well as the fact that the vast majority of potatoes are now irrigated, the irrigation water applied "efficiency" metric for potatoes (water applied per unit of production)– unlike for other crops but similar to rice – is based on the absolute yield rather than differential yield as a result of irrigation.

Volume per irrigated acre decreased slightly (2 percent, 0.1 percent compound annually); irrigation water applied averaged 21.6 acre inches per acre in 2011. Total irrigation water applied for potatoes increased 31 percent (0.9 percent compound annually) over the study period, from 14.6 million acre inches in 1980 to 21.6 million acre inches in 2011; a peak in total irrigation water applied occurred in the middle portion of the study period corresponding to a peak in overall production.

Over the study period, share of irrigated potato acreage increased from 58 percent 92 percent, driving the increase in total irrigation water applied despite decreases in total land use. Per cwt improvements have been driven primarily by improvements in yield.

See **Figures 1.40, 1.41, and 1.42** for more detail regarding the annual irrigation water applied values.

Energy Use (Potatoes)

Over the study period, energy use per cwt decreased while energy use per acre and total energy use increased for potatoes. Energy use per cwt of potatoes improved (decreased) 15 percent (0.5 percent compound annually) over the study period, from approximately 82,700 Btu per cwt in 1980 to 70,900 Btu per cwt in 2011. Energy use per acre increased 33 percent (0.9 percent compound annually), from 21.4 million Btu per acre in 1980 to 26.9 million Btu per acre in 2011. Total energy use for potatoes increased 11 percent (0.3 percent compound annually), from 25.1 trillion Btu in 1980 to 29.6 trillion Btu in 2011; a peak in total energy use occurred in the middle portion of the study period corresponding to a peak in overall production.

Storage energy for potatoes represents approximately 4 percent of total energy use; however, variations from the standard assumption of 120 days of storage that is used in this analysis could greatly impact energy use trends for potatoes.

In 2011, embedded energy in pesticides represented 12 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 that would thus drive variability in regional energy use metrics.

See **Figures 1.43, 1.44, and 1.45** for more detail regarding the annual energy use values.

Greenhouse Gas Emissions (Potatoes)

Over the study period, potatoes decreased greenhouse gas emissions per cwt and increased per acre and total emissions. Greenhouse gas emissions per cwt of potatoes improved (decreased) 22 percent (0.8 percent compound annually) over the study period; emissions were 14.3 pounds of CO_2e per cwt in 2011 compared with 18.0 pounds of CO_2e per cwt in 1980. Emissions per acre increased 23 percent (0.7 percent compound annually), from approximately 4,650 pounds of CO_2e per acre in 1980 to 5,430 pounds of CO_2e per acre in 2011. Total greenhouse gas emissions for potato production increased slightly by 3 percent (0.1 percent compound annually); potato production resulted in approximately 5.96 billion pounds of CO_2e in 2011; a peak in total emissions occurred in the middle portion of the study period corresponding to a peak in overall production.

For all crops in this report, accounting of N_2O emissions from applied nitrogen assumes a flat 1.4 percent rate irrespective of practices. However, for potatoes, given the large proportion of nitrogen that is delivered through irrigation and incrementally throughout the season, the nitrous oxide estimates in this analysis are likely higher than would be produced using a more detailed nitrous oxide approach that accounts for such variability in timing of application and other practices.

See **Figures 1.46, 1.47, and 1.48** for more detail regarding the annual greenhouse gas emission values.

Please note, in the following graphs, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

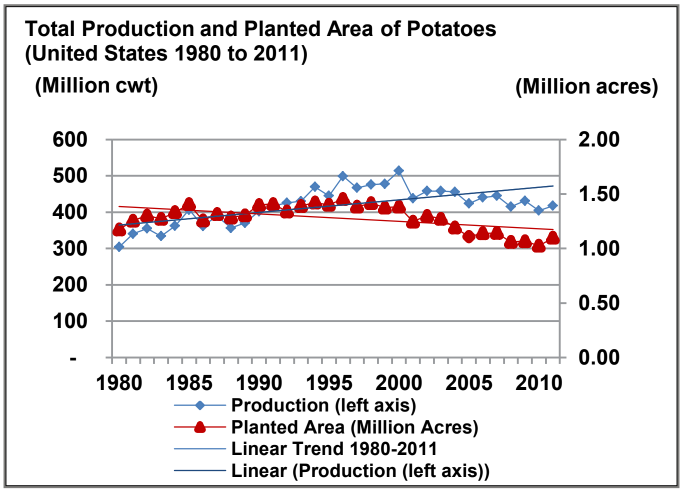


Figure 1.34 Total Production and Planted Area of Potatoes, U.S. 1980 to 2011

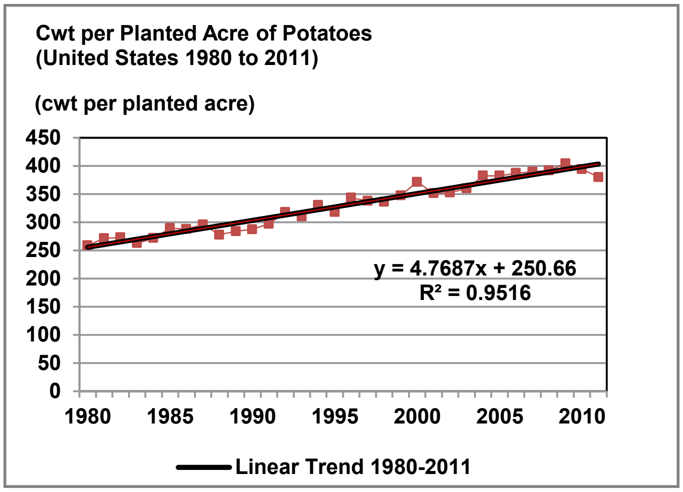


Figure 1.35 Cwt per Planted Acre of Potatoes, U.S. 1980 to 2011

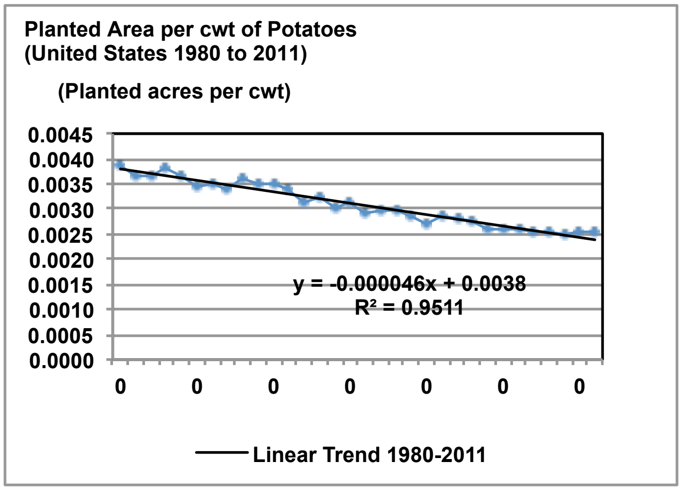


Figure 1.36 Planted Area per cwt of Potatoes, U.S. 1980 to 2011

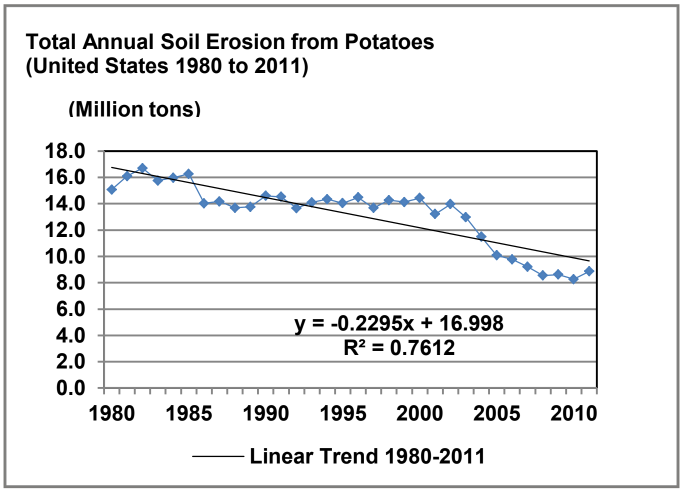


Figure 1.37 Total Annual Soil Erosion from Potatoes, U.S. 1980 to 2011

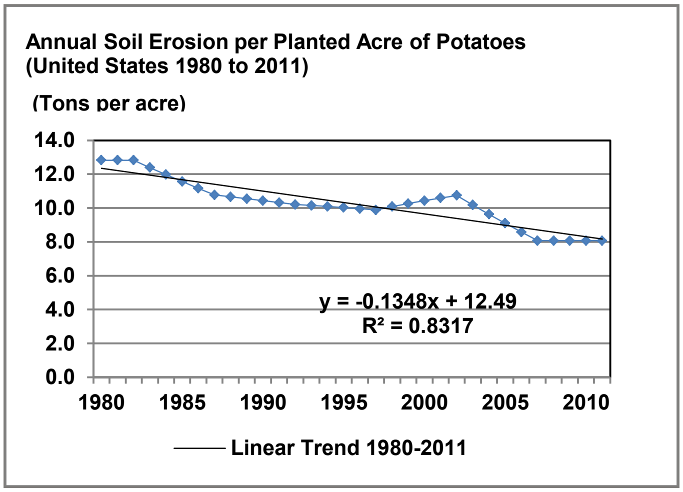


Figure 1.38 Annual Soil Erosion per Planted Acre of Potatoes, U.S. 1980 to 2011

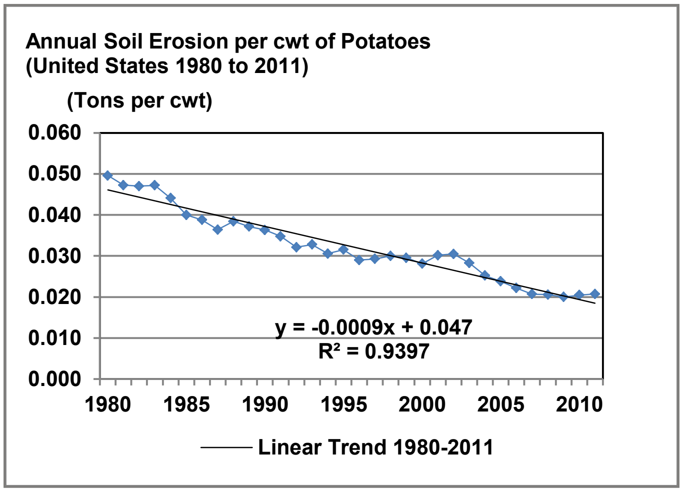


Figure 1.39 Annual Soil Erosion per cwt of Potatoes, U.S. 1980 to 2011

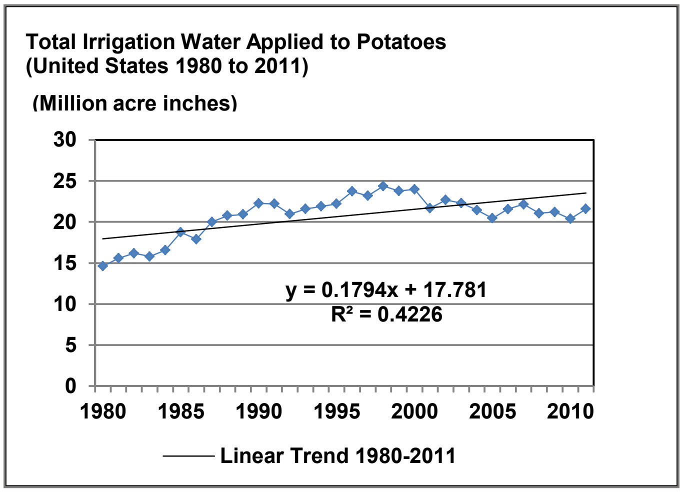


Figure 1.40 Total Irrigation Water Applied to Potatoes, U.S. 1980 to 2011

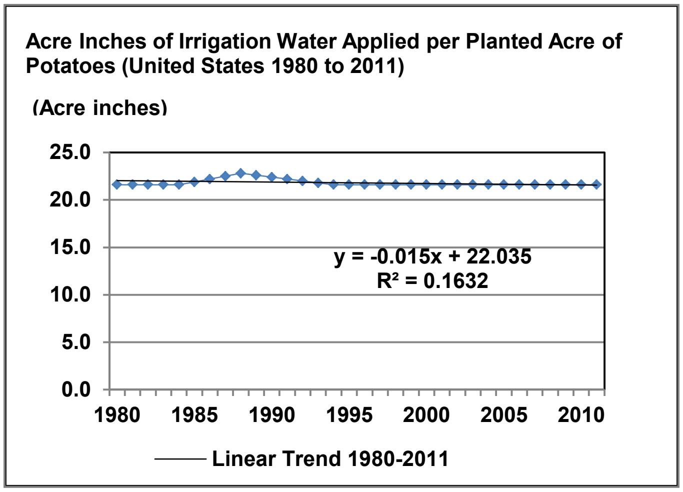


Figure 1.41 Acre Inches of Irrigation Water Applied per Planted Acre of Potatoes, U.S. 1980 to 2011

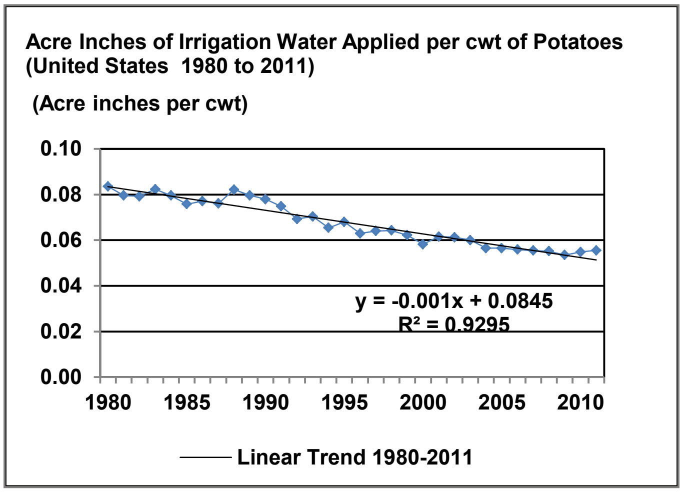
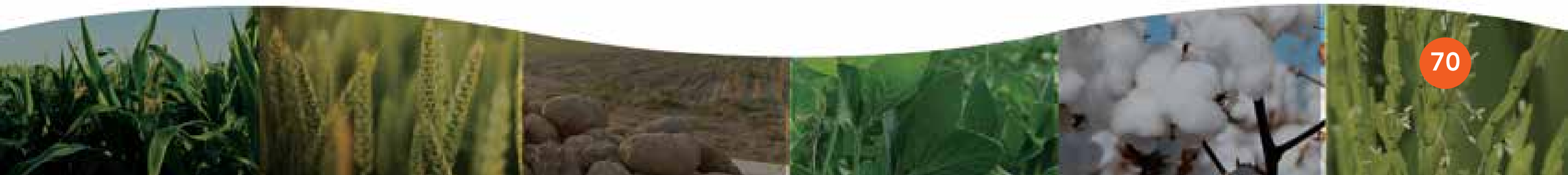


Figure 1.42 Acre Inches of Irrigation Water Applied per cwt of Potatoes, U.S. 1980 to 2011



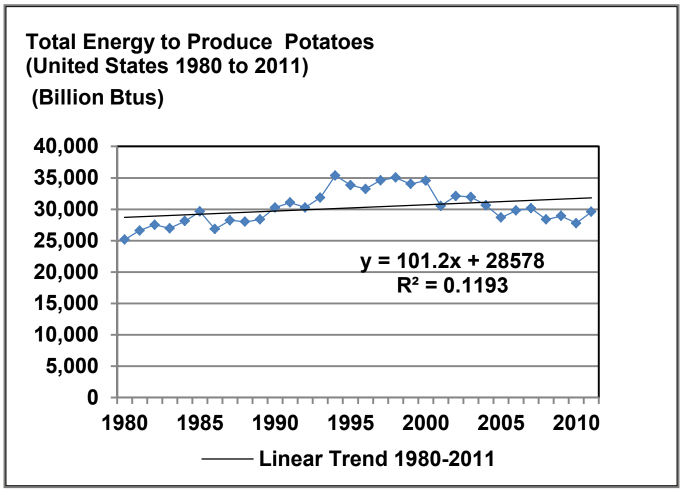


Figure 1.43 Total Energy to Produce Potatoes, U.S. 1980 to 2011

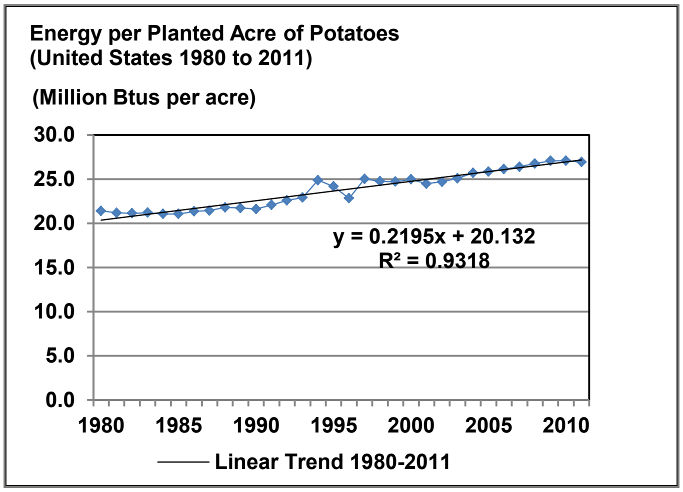


Figure I.44 Energy per Planted Acre of Potatoes, U.S. 1980 to 2011

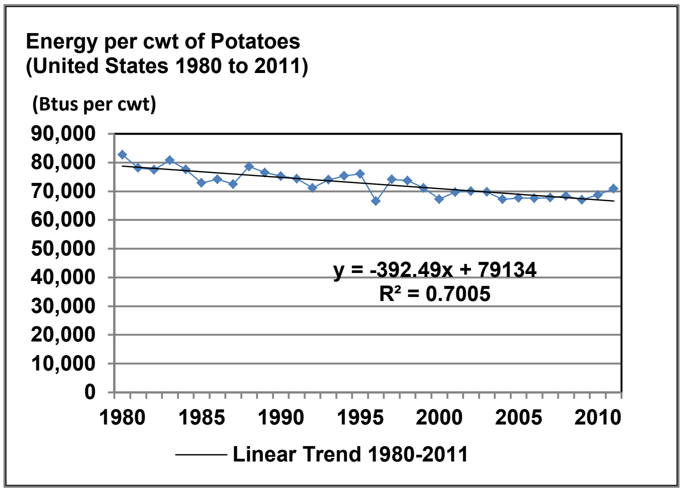


Figure 1.45 Energy per cwt of Potatoes, U.S. 1980 to 2011

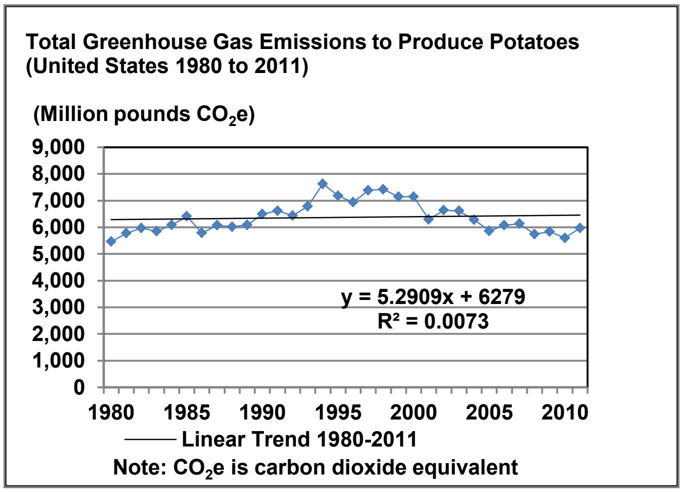


Figure 1.46 Total Greenhouse Gas Emissions to Produce Potatoes, U.S. 1980 to 2011

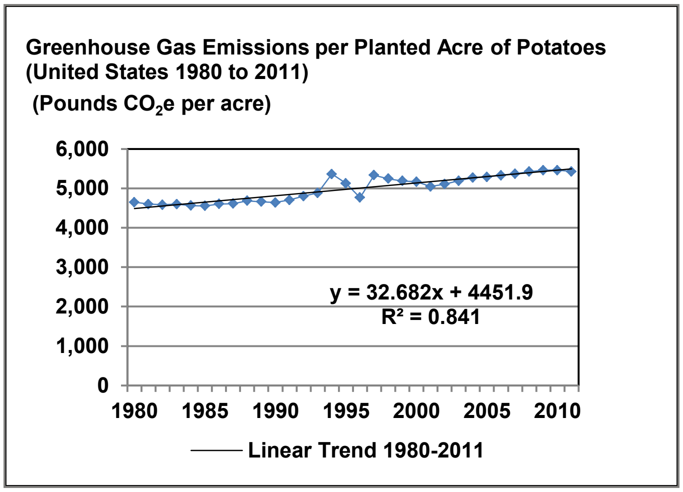


Figure 1.47 Greenhouse Gas Emissions per Planted Acre of Potatoes, U.S. 1980 to 2011

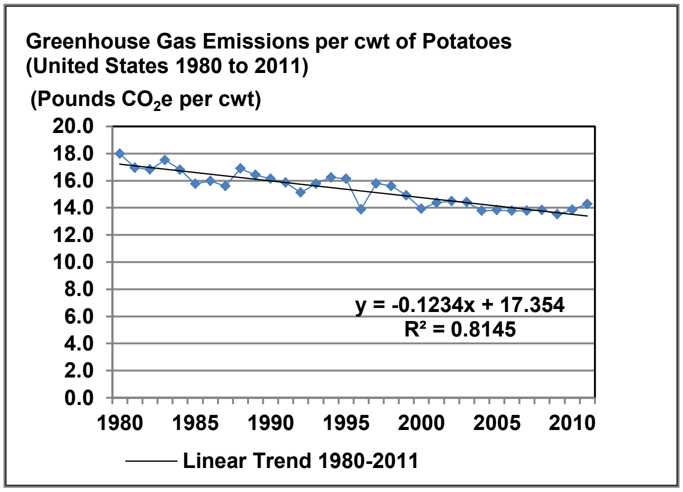


Figure 1.48 Greenhouse Gas Emissions per cwt of Potatoes, U.S. 1980 to 2011

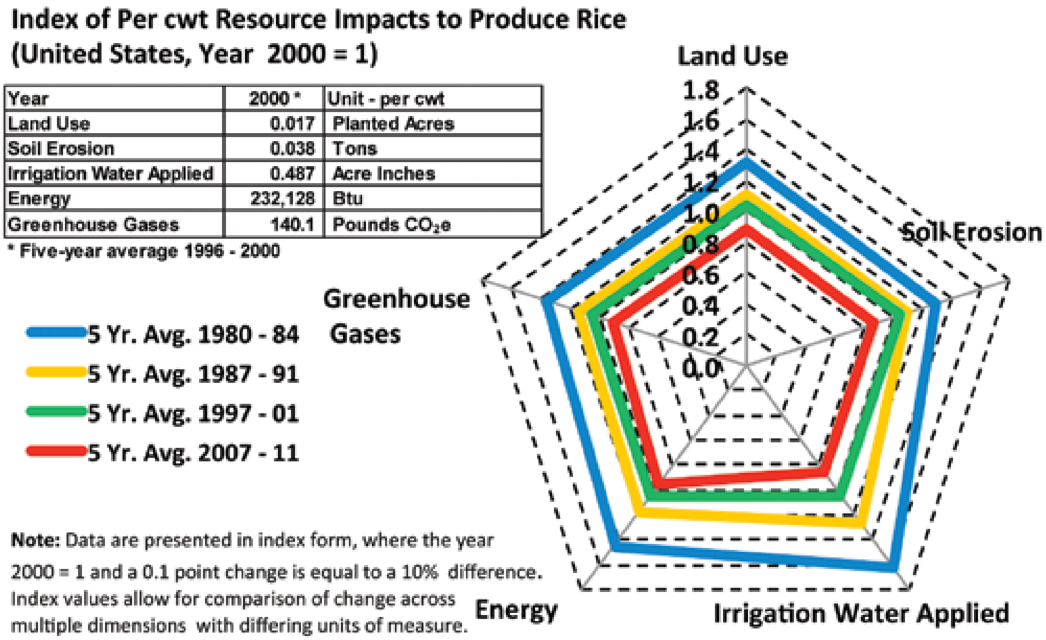
3.5. Rice Summary of Results

Overview

Over the study period (1980-2011), trends in U.S. rice production were as follows:

- **Yield:** Total rice production increased (+53%) and yield (cwt per planted acre) increased (+53%).
- **Resource efficiency (per cwt):** Rice improved on all measures of resource "efficiency," with decreases in per cwt land use (-35%), soil erosion (-34%), irrigation water applied (-53%), energy use (-38%), and greenhouse gas emissions (-38%).
- **Resource use/impact per acre:** Rice improved (decreased) per acre irrigation water applied (-25%) and slightly improved per acre energy use (-3%) and greenhouse gas emissions (-4%); per acre soil erosion remained constant (0%).
- **Total resource use/impact:** Rice improved (decreased) total irrigation water applied (-18%); rice increased total land use (+9%), soil erosion (+9%), energy use (+6%), and greenhouse gas emissions (+5%).

Summary trends for specific indicators are provided in **Figure 1.49** and **Table 1.4** and in the text below. **Figures 1.50 through 1.64** demonstrate linear trends over the full study period for total, per acre, and per unit of production resource use/impacts. Average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted below.



Index of Per cwt Resource Impacts to Produce Rice (United States, Year 2000 = 1)

Year	2000 *	Unit - per cwt
Land Use	0.017	Planted Acres
Soil Erosion	0.038	Tons
Irrigation Water Applied	0.487	Acre Inches
Energy	232,128	Btu
Greenhouse Gases	140.1	Pounds CO_2e

* Five-year average 1996 - 2000

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

Figure 1.49 Index of Per cwt Resource Impacts to Produce Rice, United States, 1980-2011

Table 1.4 Rice Summary of Results

Rice Summary of Results: Trends in U.S. Production, Resource Use / Impact, 1980-2011				
Resource Area	Indicator	Percent Change* 1980-2011		
		Trend Direction	Entire Period	Compound Annual
Crop Yield	Total Production	↑	53	1.4
	Cwt per Acre	↑	53	1.4
Land Use	Total Planted Acres	↑	9	0.3
	Acres per Cwt	↓	(35)	(1.4)
Soil Erosion	Total Tons	↑	9	0.3
	Tons per Acre	↓	(0)	(0.0)
	Tons per Cwt	↓	(34)	(1.3)
Irrigation Water Applied	Total Volume	↓	(18)	(0.6)
	Volume per Irrigated Acre	↓	(25)	(0.9)
	Volume per Cwt	↓	(53)	(2.4)
Energy Use	Total Btu	↑	6	0.2
	Btu per Acre	↓	(3)	(0.1)
	Btu per Cwt	↓	(38)	(1.5)
GHG Emissions (CO_2 Equivalents)	Total Pounds	↑	5	0.2
	Pounds per Acre	↓	(4)	(0.1)
	Pounds per Cwt	↓	(38)	(1.5)

*Percent change results are based on a least squares trends analyses from 1980 - 2011

Sources: Calculations are based on a number of data sources, including: 1. USDA, NASS, Census of Agriculture, Farm and Ranch Irrigation Survey, http://www.agcensus.usda.gov/Publications/index.php; 2. USDA, Economic Research Service (ERS), Agricultural Resource Management Survey (ARMS) http://www.ers.usda.gov/Briefing/ARMS/Access.htm; 3. USDA, National Resources Conservation Service (NRCS), National Resource Inventory (NRI) Reports http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri

Total Production and Yield (Rice)

Total production and yield for rice increased over the study period. Total production of rice increased by 53 percent, or 1.4 percent compound annually; 185 million cwt of rice were produced in 2011 as compared with 146 million cwt of rice produced in 1980. Yield (cwt per planted acre) increased 53 percent over the study period, or 1.4 percent compound annually; average planted acre yield in 2011 was 68.8 cwt per planted acre as compared with 43.2 cwt per planted acre in 1980. Harvested yield was 70.7 cwt per harvested acre in 2011.

Land Use (Rice)

Total planted acreage increased for rice and acres per cwt decreased over the study period. Total planted acreage of rice increased by an average trend of 9 percent, or 0.3 percent compound annually, with variability over time; 2.69 million acres of rice were planted in 2011, compared to highs of 3.83 million acres and 3.64 million acres in 1981 and 2010, respectively, and a low of 2.19 million acres in 1983. Harvested acreage in 2011 was 2.6 million acres; rice typically experiences minimal abandonment. Over the study period, the land use "efficiency" metric (planted acres per cwt) improved (decreased) by 35 percent, or 1.4 percent compound annually.

See **Figures 1.50, 1.51, and 1.52** for more detail regarding the annual land use, production, and yield values.

Soil Erosion (Rice)

Soil erosion per acre remained constant, soil erosion per cwt decreased, and total soil erosion increased for rice over the study period. On a per acre basis, rice consistently demonstrates the lowest per acre soil erosion of all 6 crops examined (slightly above 2 tons/acre, not relative to T). (Note: Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre). This is due in part to the cultivation practices employed that are unique to rice, particularly flood irrigation and land leveling practices.

Per acre soil erosion remained constant over the study period. Soil erosion (tons) per cwt of rice improved (decreased) 34 percent over the study period (1.3 percent compound annually) due to increases in productivity. Total tons of soil erosion for rice increased 9 percent (0.3 percent compound annually), with variability over time in correlation with variability in planted acreage; total erosion was 5.9 million tons in 2011.

See **Figures 1.53, 1.54 and 1.55** for more detail regarding the annual soil erosion values.

Irrigation Water Applied (Rice)

Irrigation water applied for rice improved on all measures. Over the study period, rice improved (decreased) its volume per cwt (53 percent, 2.4 percent compound annually), from 0.80 acre inches per cwt in 1980 to 0.40 acre inches per cwt in 2011. Rice improved its volume per acre (25 percent, 0.9 percent compound annually), from 34.8 acre inches in 1980 to 27.6 acre inches in 2011. Total irrigation water applied decreased (18 percent, 0.6 compound annually), from 118 million acre inches in 1980 to 74 million acre inches in 2011.

Please note: because all rice is irrigated, the irrigated water use "efficiency" metric for rice (water applied per unit of production) – unlike for other crops but similar to potatoes – is based on the absolute yield rather than differential yield as a result of irrigation.

Adoption of practices and infrastructure to use reclaimed and recycled water for rice production nationwide has also increased water use efficiency over the study period; however, because this study focuses on amount of water applied rather than source of water, and due to limitations of the data, these improvements are not reflected in our analysis.

See **Figures 1.56, 1.57, and 1.58** for more detail regarding the annual irrigation water applied values.

Energy Use (Rice)

Energy use for rice decreased per cwt and per acre and total energy use increased over the study period. Energy use per cwt of rice production improved (decreased) 38 percent (1.5 percent compound annually) over the study period, primarily due to productivity gains; energy use was approximately 341,000 Btu per cwt in 1980 and 212,000 Btu per cwt in 2011. Energy use per acre decreased slightly, by 3 percent (0.1 percent compound annually); average energy use per acre was 14.6 million Btu in 2011. Total energy use for rice production increased an average of 6 percent (0.2 percent compound annually) over the study period, however, relative to the average trend line, there was variability throughout the study period and total energy use for rice was 39.3 trillion Btu in 2011 compared with a high of 56.4 trillion Btu in 1981 and a low of 33.7 trillion Btu in 1983.

See **Figures 1.59, 1.60 and 1.61** for more detail regarding the annual energy use values.

Greenhouse Gas Emissions (Rice)

Greenhouse gas emissions for rice decreased per cwt and per acre and total greenhouse gas emissions increased over the study period. Greenhouse gas emissions per cwt of rice improved (decreased) 38 percent (1.5 percent compound annually) over the study period, primarily due to improvements in productivity; emissions were approximately 193 pounds CO_2e per cwt in 1980 and 123 pounds CO_2e per cwt in 2011. Emissions per acre decreased by 4 percent (0.1 percent compound annually); emissions were approximately 8,450 pounds CO_2e per acre in 2011. Total greenhouse gas emissions for rice production increased by an average of 5 percent (0.2 percent compound annually), however, relative to the average trend line, there was variability through the study period; total emissions were approximate 22.7 billion pounds CO_2e in 2011 compared with a high of 32.4 billion pounds CO_2e in 1981 and a low of 18.8 billion pounds CO_2e in 1983.

See **Figures 1.62, 1.63 and 1.64** for more detail regarding the annual greenhouse gas emissions values.

Please note, in the following graphs, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

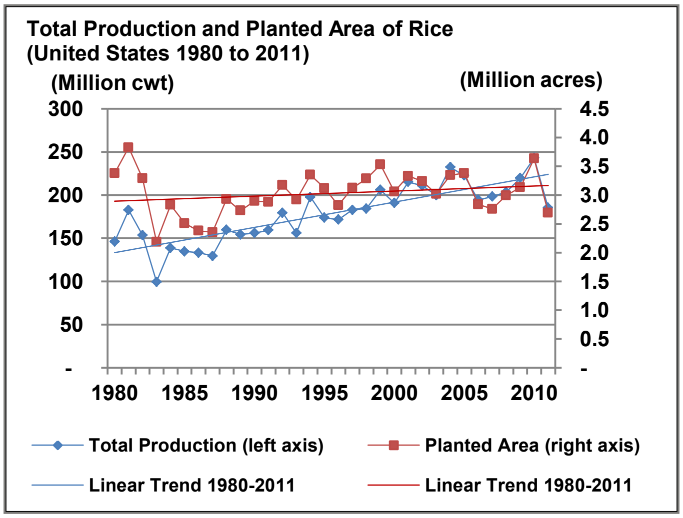


Figure 1.50 Total Production and Planted Area of Rice, U.S. 1980 to 2011

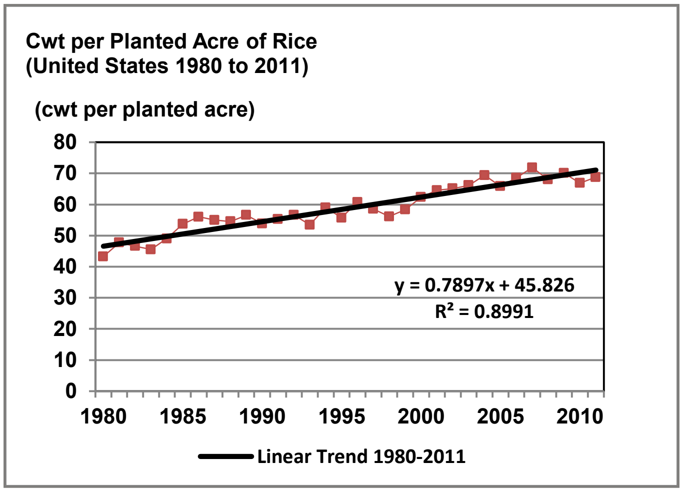


Figure 1.51 Cwt per Planted Acre of Rice, U.S. 1980 to 2011

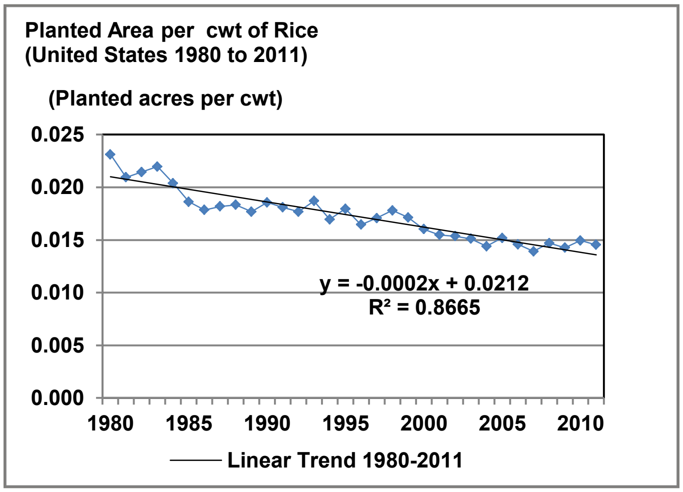


Figure 1.52 Planted Area per cwt of Rice, U.S. 1980 to 2011

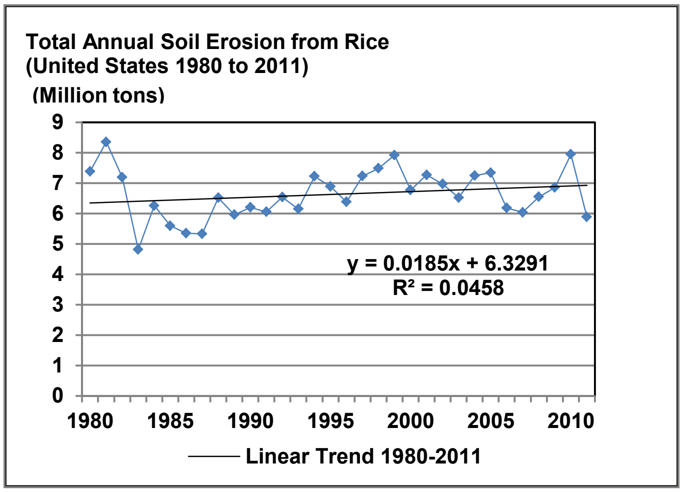


Figure 1.53 Total Annual Soil Erosion from Rice, U.S. 1980 to 2011

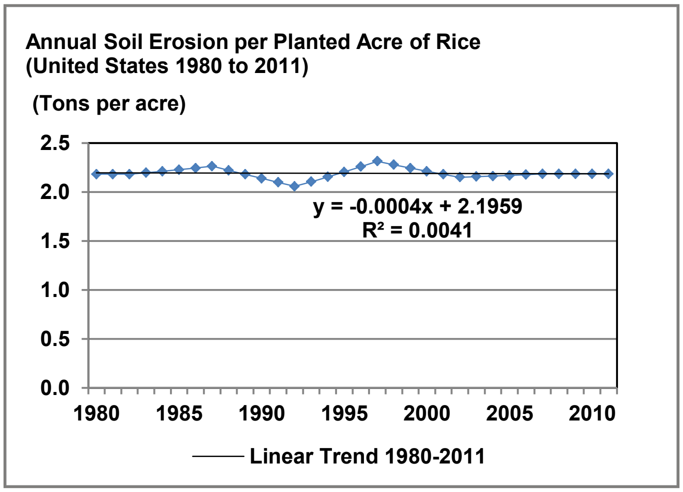


Figure 1.54 Annual Soil Erosion per Planted Acre of Rice, U.S. 1980 to 2011

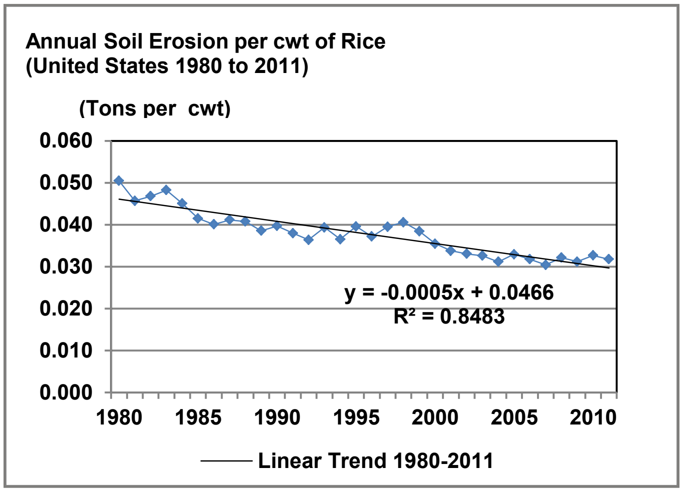


Figure 1.55 Annual Soil Erosion per cwt of Rice, U.S. 1980 to 2011

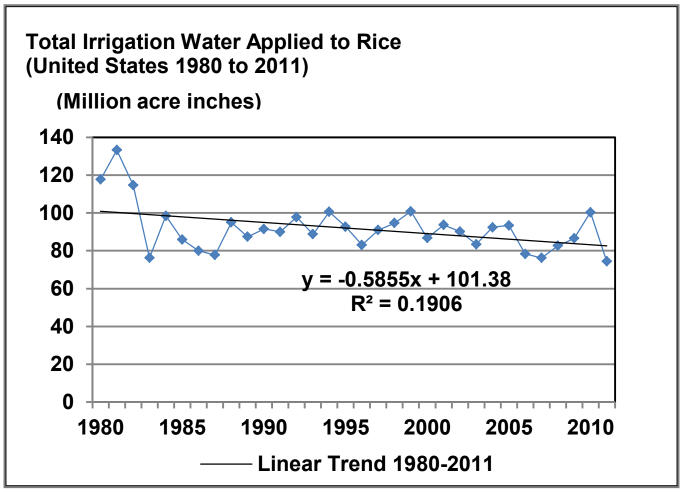


Figure 1.56 Total Irrigation Water Applied to Rice, U.S. 1980 to 2011

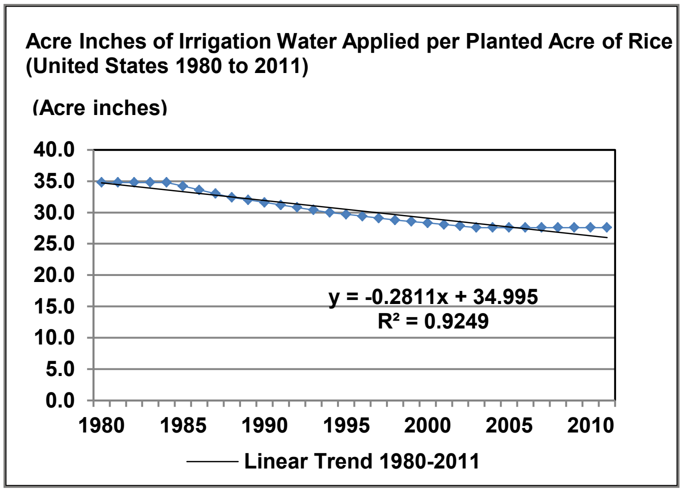


Figure 1.57 Acre Inches of Irrigation Water Applied per Planted Acre of Rice, U.S. 1980 to 2011

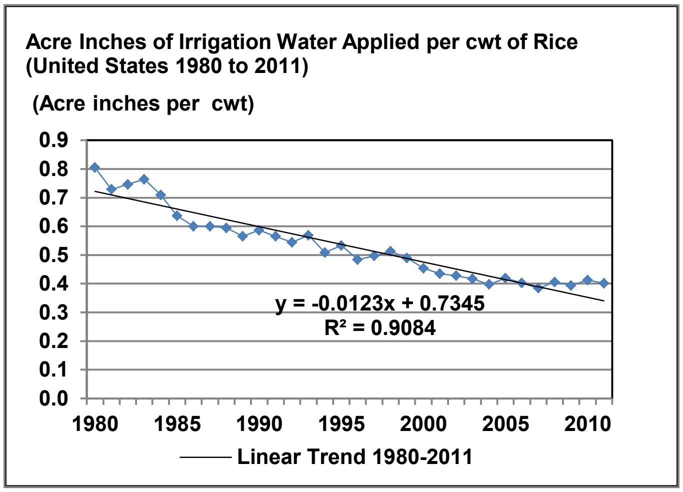


Figure 1.58 Acre Inches of Irrigation Water Applied per cwt of Rice, U.S. 1980 to 2011

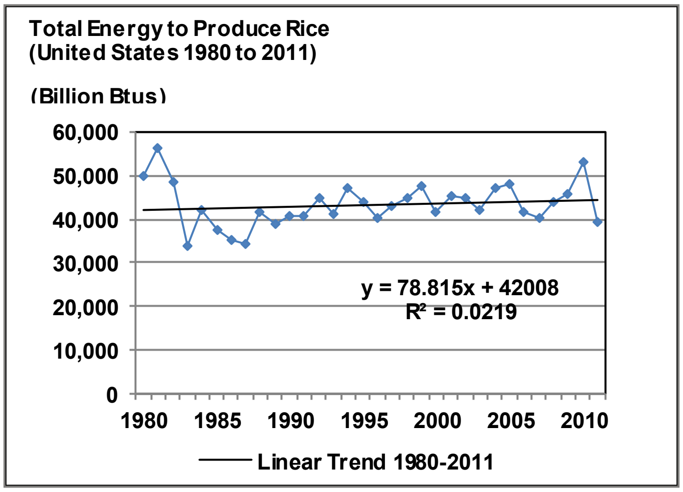


Figure 1.59 Total Energy to Produce Rice, U.S. 1980 to 2011

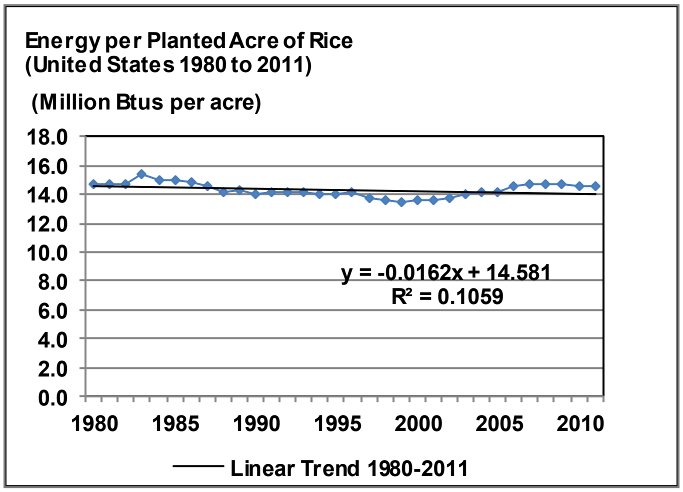


Figure 1.60 Energy per Planted Acre of Rice, U.S. 1980 to 2011

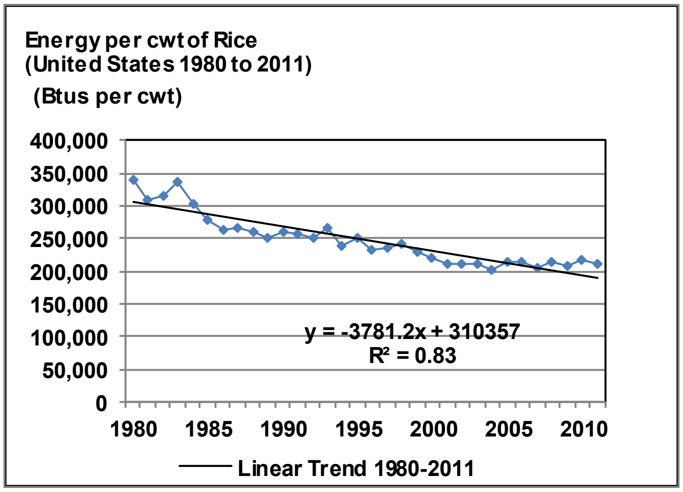


Figure 1.61 Energy per cwt of Rice, U.S. 1980 to 2011

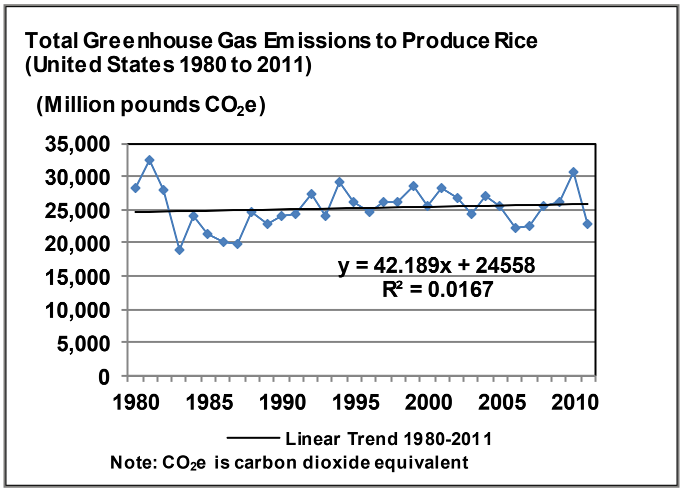


Figure 1.62 Total Greenhouse Gas Emissions to Produce Rice, U.S. 1980 to 2011

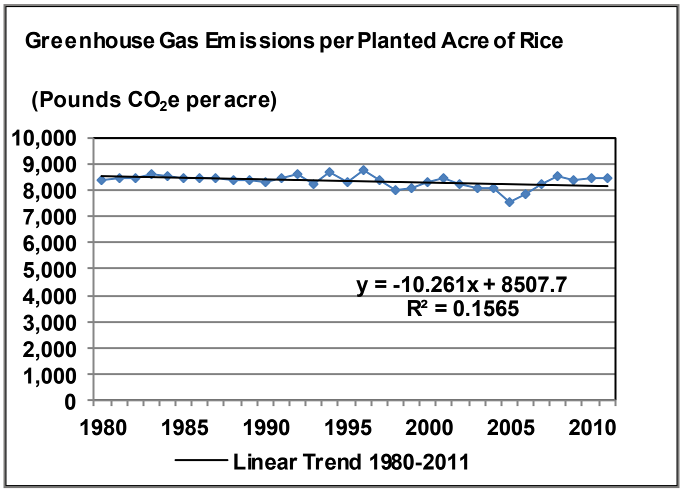


Figure 1.63 Greenhouse Gas Emissions per Planted Acre of Rice, U.S. 1980 to 2011

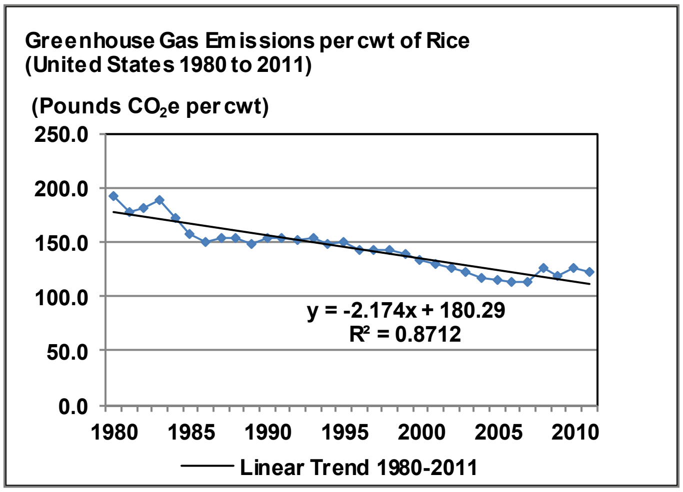
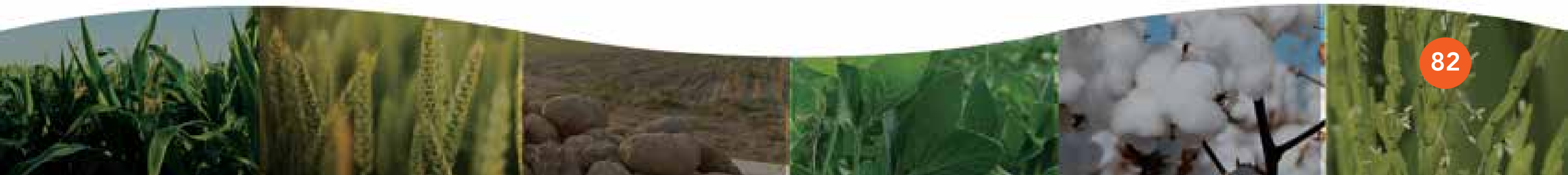


Figure 1.64 Greenhouse Gas Emissions per cwt of Rice, U.S. 1980 to 2011



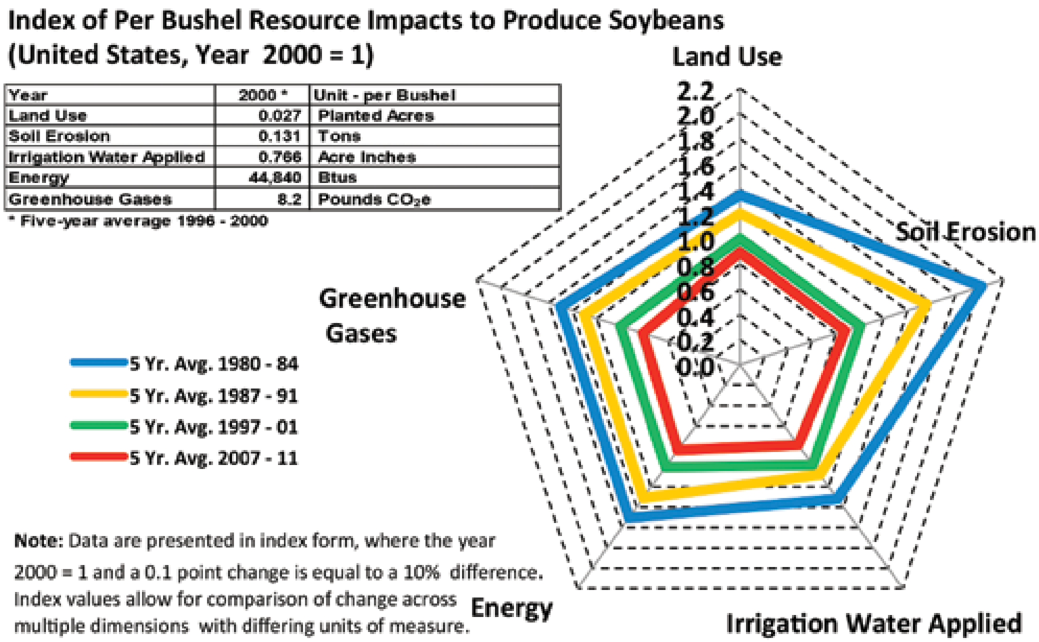
3.6. Soybeans Summary of Results

Overview

Over the study period (1980-2011), trends in U.S. soybean production were as follows:

- **Yield:** Total soybean production increased (+96%) and yield (bushels per planted acre) increased (+55%).
- **Resource efficiency (per bushel):** Soybeans improved on all measures of resource "efficiency," with decreases in per bushel land use (-35%), soil erosion (-66%), irrigation water applied (-42%) , energy use (-48%), and greenhouse gas emissions (-49%).
- **Resource use/impact per acre:**Soybeans improved (decreased) per acre soil erosion (-41%), irrigation water applied (-9%), energy use (-17%), and greenhouse gas emissions (-18%). Improvements in per acre soil erosion occurred primarily in the first half of the study period; per acre soil erosion has remained relative constant since the mid-1990s.
- **Total resource use/impact:** Soybeans improved (decreased) total soil erosion (-28%) and increased total land use (+24%) and irrigation water applied (+271%);soybeans experienced slight increases in total energy use (+3%) and greenhouse gas emissions (+1%). Improvements in total soil erosion occurred primarily in the first half of the study period, with more recent trends indicating a slight increase in total annual erosion.

Summary trends for specific indicators are provided in **Figure 1.65** and **Table 1.5** and in the text below. **Figures 1.66 through 1.80** demonstrate linear trends over the full study period for total, per acre, and per unit of production resource use/impacts. Average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted below.



Year	2000 *	Unit - per Bushel
Land Use	0.027	Planted Acres
Soil Erosion	0.131	Tons
Irrigation Water Applied	0.766	Acre Inches
Energy	44,840	Btus
Greenhouse Gases	8.2	Pounds CO_2e

* Five-year average 1996 - 2000

Figure 1.65 Index of Per Bushel Resource Impacts to Produce Soybeans, United States, 1980-2011

Table 1.5 Soybeans Summary of Results

Soybeans Summary of Results:
Trends in U.S. Production, Resource Use / Impact, 1980-2011

Resource Area	Indicator	Percent Change* 1980-2011		
		Trend Direction	Entire Period	Compound Annual
Crop Yield	Total Production	↑	96	2.2
	Bushels per Acre	↑	55	1.4
Land Use	Total Planted Acres	↑	24	0.7
	Acres per Bushel	↓	(35)	(1.4)
Soil Erosion	Total Tons	↓	(28)	(1.0)
	Tons per Acre	↓	(41)	(1.7)
	Tons per Bushel	↓	(66)	(3.5)
Irrigation Water Applied	Total Volume	↑	271	4.3
	Volume per Irrigated Acre	↓	(9)	(0.3)
	Volume per Bushel	↓	(42)	(1.8)
Energy Use	Total Btu	↑	3	0.1
	Btu per Acre	↓	(17)	(0.6)
	Btu per Bushel	↓	(48)	(2.1)
GHG Emissions (CO_2 Equivalents)	Total Pounds	↑	1	0.0
	Pounds per Acre	↓	(18)	(0.6)
	Pounds per Bushel	↓	(49)	(2.1)

*Percent change results are based on a least squares trends analyses from 1980 - 2011

Sources: Calculations are based on a number of data sources: 1. USDA, NASS, Census of Agriculture, Farm and Ranch Irrigation Survey, http://www.agcensus.usda.gov/Publications/index.php 2. USDA, Economic Research Service (ERS), Agricultural Resource Management Survey (ARMS) http://www.ers.usda.gov/Briefing/ARMS/Access.htm 3. USDA, National Resources Conservation Service (NRCS), National Resrouce Inventory (NRI) Reports http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri

Total Production and Yield (Soybeans)

Total production and yield of soybeans increased over the study period. Total production of soybeans increased over the study period by 96 percent, or 2.2 percent compound annually; 3.06 billion bushels of soybean were produced in 2011 as compared with 1.80 billion bushels in 1980. Yield (bushels per planted acre) increased 55 percent over the study period, or 1.4 percent compound annually; average planted yield in 2011 was 40.8 bushels per planted acre as compared with 25.7 bushels per planted acre in 1980. Harvested yield was 41.5 bushels per harvested acre in 2011.

Land Use (Soybeans)

Total planted acreage increased and acres per bushel decreased over the study period. Total planted acreage of soybeans increased over the study period by 24 percent, or 0.7 percent compound annually; 75.0 million acres of soybeans were planted in 2011 as compared with 69.9 million planted acres in 1980. Harvested acreage was 73.6 million acres for soybeans in 2011. Soybeans experience minimal abandonment. Over the study period, the land use "efficiency" metric (acres per bushel) improved (decreased) 35 percent, or 1.4 percent compound annually.

See **Figures 1.66, 1.67 and 1.68** for more detail regarding the annual land use, production, and yield values.

Soil Erosion (Soybeans)

Soil erosion for soybeans improved for all measures. Total tons of soil erosion for soybeans decreased 28 percent over the study period, or 1.0 percent compound annually, from 519 million tons in 1980 to 360 million tons in 2010. In absolute terms (not relative to a tolerance rate or T), per acre soil erosion decreased from more than 7 tons per acre to 4.80 tons per acre, or 41 percent (1.7 percent compound annually). (Note: Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre). Tons per bushel decreased 66 percent (3.5 percent compound annually).

Adoption of no-till practices for soybeans has been more pervasive than for any other crop in the United States, helping to drive improvements in soil erosion. Much improvement was seen in the first half of the study period; trends in improvement in total and per acre soil loss have slowed since the mid-1990s.

While the average trend since 1980 shows significant improvement in total and per acre soil erosion, these improvements occurred primarily before the mid-1990s, likely attributable in large part to implementation of conservation plans, particularly on highly erodible lands. Since the mid-1990s, per acre erosion for soybeans has remained relatively constant; however, total soil erosion has increased in correlation with increases in total planted acreage.

See **Figures 1.69, 1.70 and 1.71** for more detail regarding the annual soil erosion values.

Irrigation Water Applied (Soybeans)

Irrigation water applied decreased per acre and per bushel and total irrigation water applied increased over the study period. Soybeans decreased volume of water applied per irrigated acre (9 percent, 0.3 percent compound annually), from approximately 9.6 acre inches in 1980 to 8.4 acre inches in 2011. Volume per incremental bushel produced as a result of irrigation also improved (decreased) (42 percent, 1.8 percent compound annually), from 1.09 acre inches per bushel in 1980 to 0.60 acre inches per bushel in 2011. Total irrigation water applied for soybeans increased 271 percent (4.3 compound annually) over the study period; from 24.2 million acre inches in 1980 to 58.6 million acre inches in 2011.

The incidence of irrigation water applied for soybeans has increased steadily over the study period; less than 4 percent of soybean acreage was irrigated in 1980 as compared to more than 9 percent in 2011; the increase in proportion of irrigated acres corresponds with an increase in total planted soybean acres, thus driving increases in total irrigation water applied. However, per acre irrigation water applied for those acres that are irrigated has remained relatively flat.
See **Figures 1.72, 1.73 and 1.74** for more detail regarding the annual irrigation water applied values.

Energy Use (Soybeans)

Energy use decreased per bushel and per acre and total energy use increased slightly for soybeans over the study period. Energy use per bushel of soybeans improved (decreased) 48 percent (2.1 percent compound annually) over the study period, from 74,000 Btu per bushel in 1980 to 36,800 Btu per bushel in 2011. Energy use per acre decreased 17 percent (0.6 percent compound annually), from 1.9 million Btu per acre in 1980 to 1.5 million Btu per acre in 2011. Total energy use for soybeans increased 3 percent (0.1 percent compound annually). However, actual values for total energy use are less linear, punctuated by a decrease from 1980 to 1993 and a more rapid increase between ~1993 and 2004, followed by a more recent decrease. The 2011 value for total energy (113 trillion Btu) is actually less than the 1980 value (133 trillion Btu).

Energy use for crop chemicals (embedded energy) and irrigation for soybeans have increased over time, however these increases have been offset by decreases in tillage energy.

See **Figures 1.75, 1.76 and 1.77** for more detail regarding the annual energy use values.

Greenhouse Gas Emissions (Soybeans)

Greenhouse gas emissions decreased per bushel and per acre over the study period while total emissions remained nearly constant. Emissions per bushel of soybeans improved (decreased) 49 percent (2.1 percent compound annually) over the study period, from 13.6 pounds CO2e per bushel in 1980 to 6.5 pounds CO2e per bushel in 2011. Emissions per acre decreased by 18 percent (0.6 percent compound annually), from 351 pounds CO2e per acre in 1980 to 267 pounds CO2e per acre in 2011. Total greenhouse gas emissions for soybean production remained nearly constant, increasing 1 percent (0.0 percent compound annually), however, similar to energy use, actual values for total emissions are less linear, punctuated by a decrease from 1980 to 1992 and a more rapid increase between ~1992 and 2004, followed by a more recent decrease. The 2011 value for total emissions (20.0 billion pounds CO2e) is actually less than the 1980 value (24.5 billion pounds CO2e); total emissions peaked at 25.0 billion pounds CO2e in 2004.

Greenhouse gas emissions associated with crop chemicals (embedded energy) and irrigation have increased over time. However these increases have been offset by decreases in emissions associated with tillage operations.

See **Figures 1.78, 1.79 and 1.80** for more detail regarding the annual greenhouse gas emissions values.

Please note, in the following graphs, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

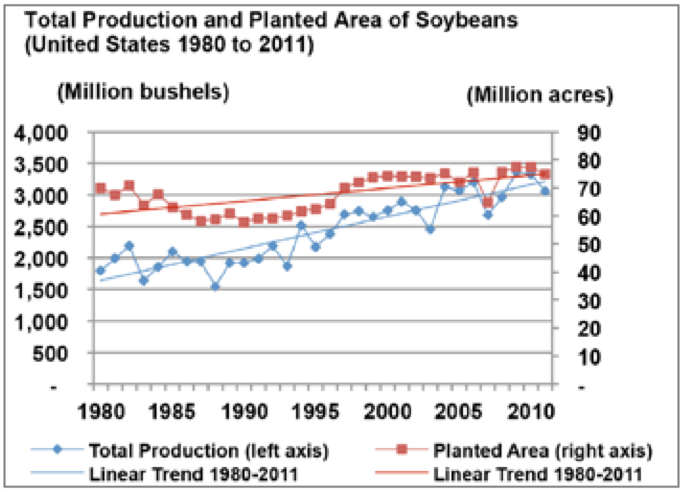


Figure 1.66 Total Production and Planted Area of Soybeans, U.S. 1980 to 2011

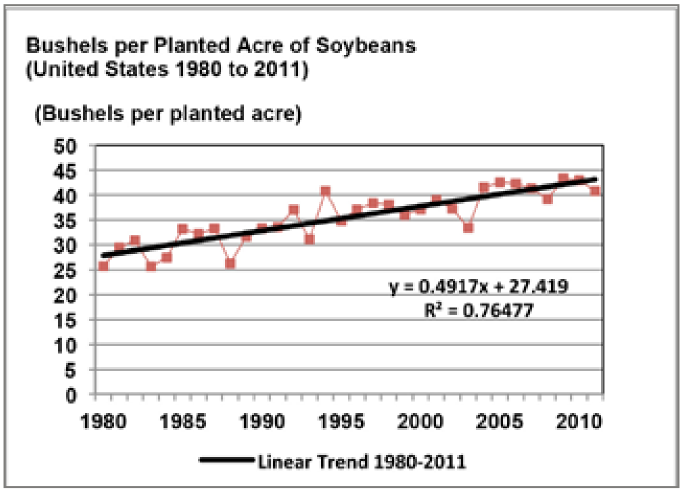


Figure 1.67 Bushels per Planted Acre of Soybeans, U.S. 1980 to 2011

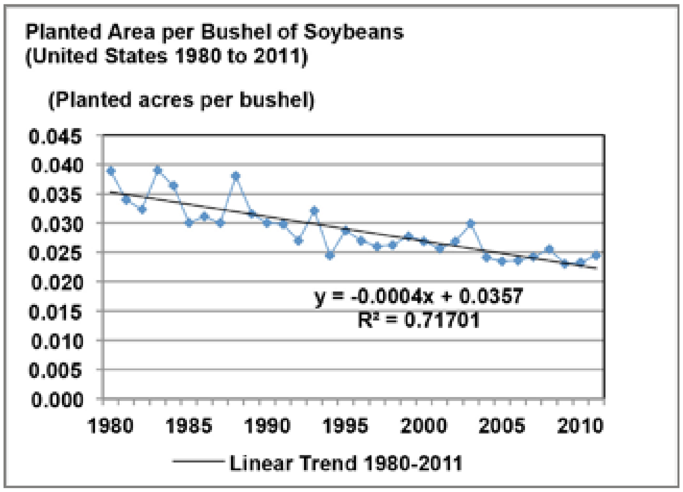


Figure 1.68 Planted Area per Bushel of Soybeans, U.S. 1980 to 2011

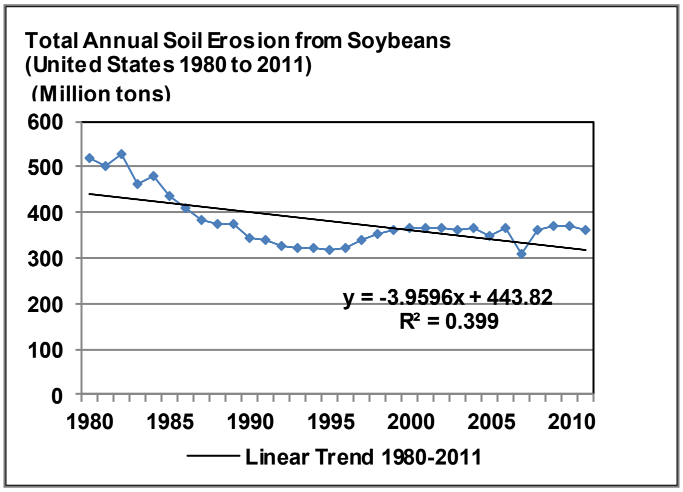


Figure 1.69 Total Annual Soil Erosion from Soybeans, U.S. 1980 to 2011

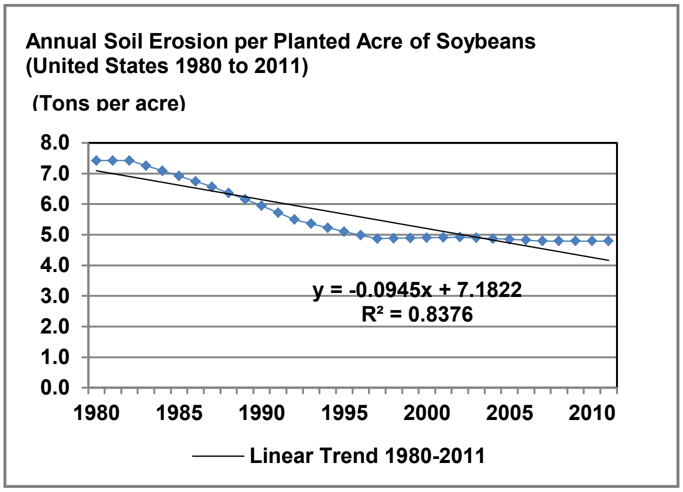


Figure 1.70 Annual Soil Erosion per Planted Acre of Soybeans, U.S. 1980 to 2011

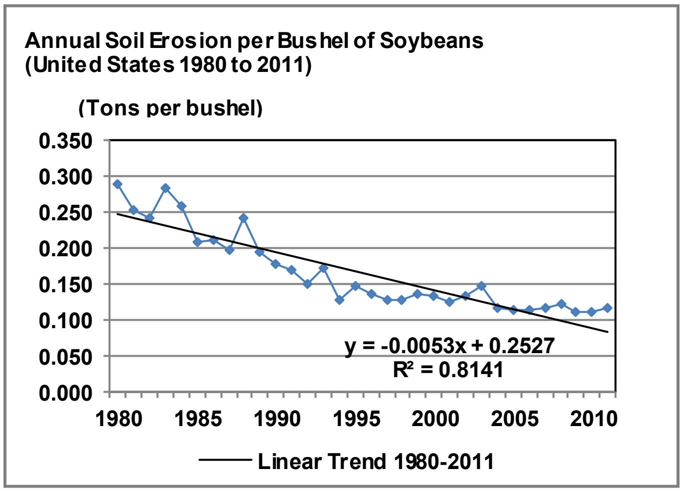
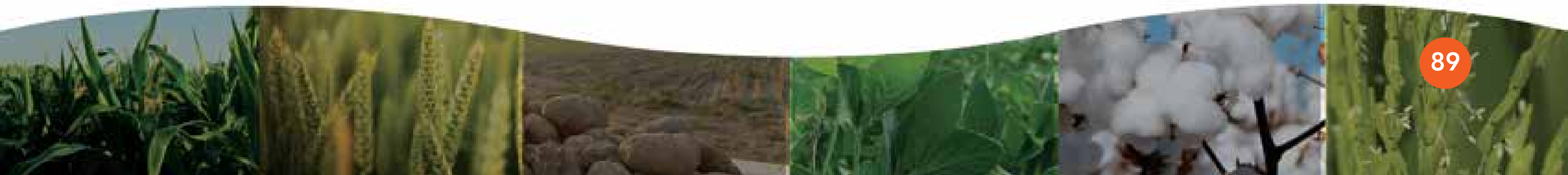


Figure 1.71 Annual Soil Erosion per Bushel of Soybeans, U.S. 1980 to 2011



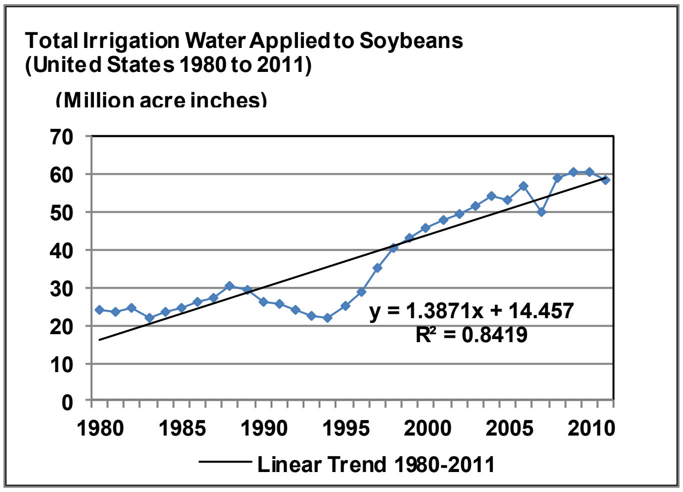


Figure 1.75 Total Energy to Produce Soybeans, U.S. 1980 to 2011

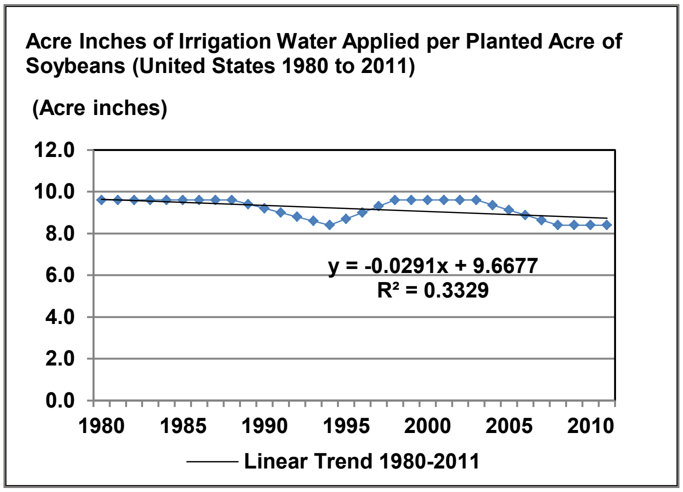


Figure 1.76 Energy per Planted Acre of Soybeans, U.S. 1980 to 2011

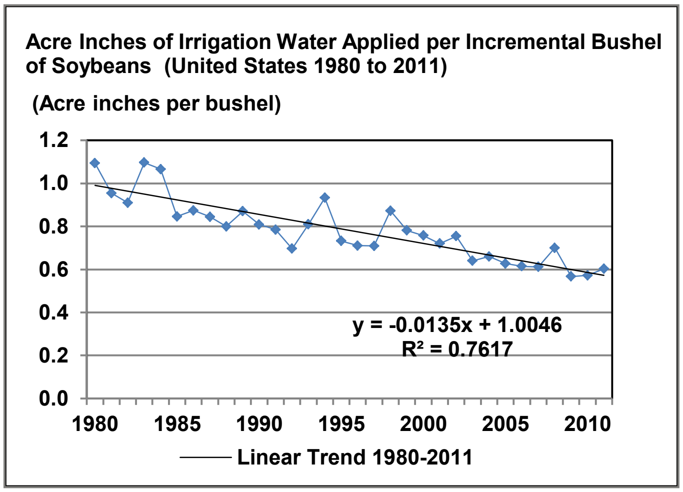


Figure 1.77 Energy per Bushel of Soybeans, U.S. 1980 to 2011

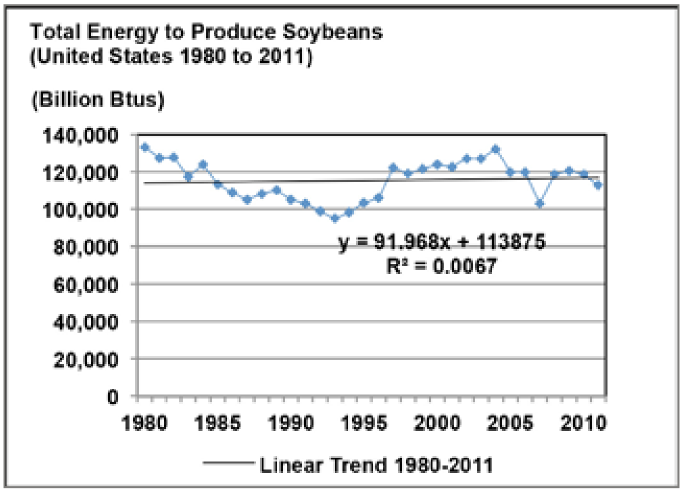


Figure 1.75 Total Energy to Produce Soybeans, U.S. 1980 to 2011

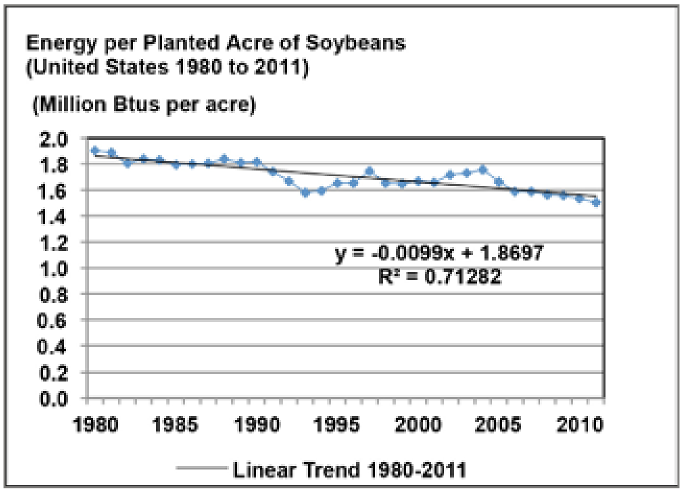


Figure 1.76 Energy per Planted Acre of Soybeans, U.S. 1980 to 2011

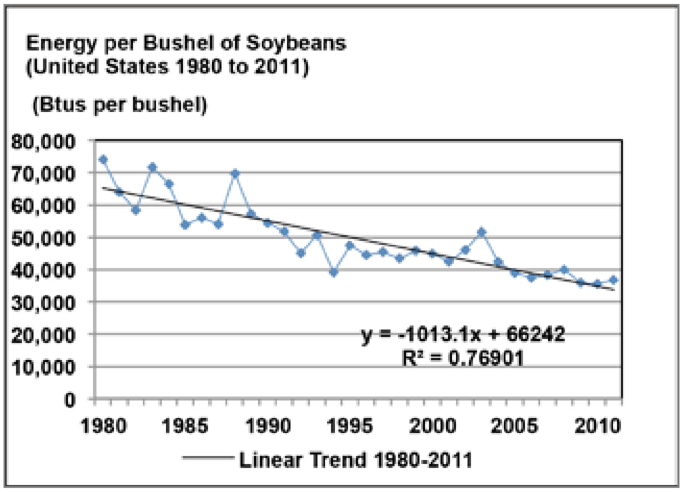


Figure 1.77 Energy per Bushel of Soybeans, U.S. 1980 to 2011

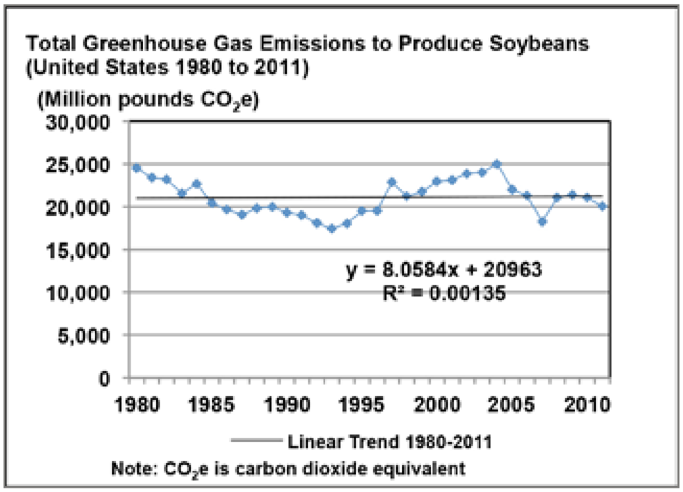


Figure 1.78 Total Greenhouse Gas Emissions to Produce Soybeans, U.S. 1980 to 2011

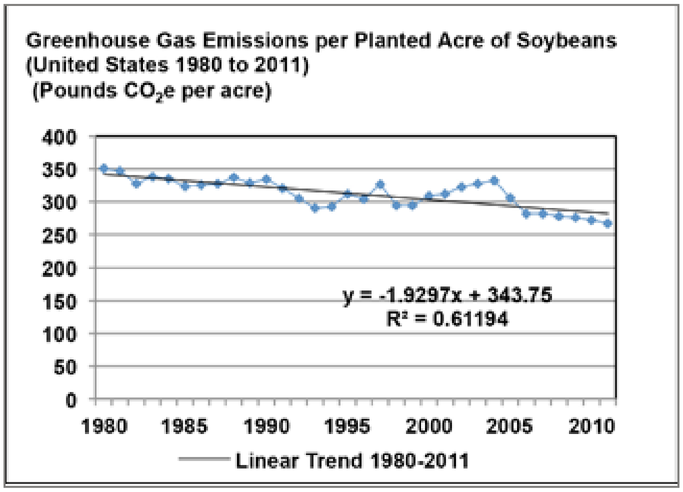


Figure 1.79 Greenhouse Gas Emissions per Planted Acre of Soybeans, U.S. 1980 to 2011

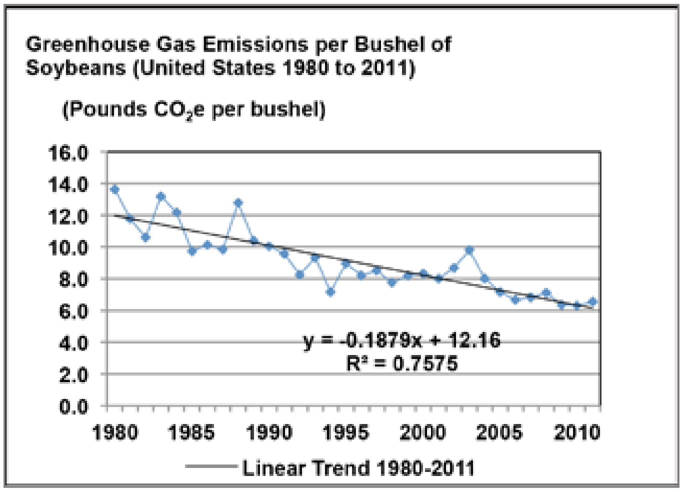


Figure 1.80 Greenhouse Gas Emissions per Bushel of Produce Soybeans, U.S. 1980 to 2011

3.7. Wheat Summary of Results

Overview

Over the study period (1980-2011), trends in U.S. wheat production were as follows:

- **Yield:** Total wheat production decreased (-16%) and yield per planted acre increased (+25%).
- **Resource efficiency (per bushel):** Wheat improved on all measures of resource "efficiency," with decreases in per bushel land use (-18%), soil erosion (-47%), irrigation water applied (-12%), energy use (-12%), and greenhouse gas emissions (-2%).
- **Resource use/impact per acre:** Wheat improved (decreased) per acre soil erosion (-34%); wheat increased per acre irrigation water applied (+6%), energy use (+9%) and greenhouse gas emissions (+21%). Per acre soil erosion improvements were realized primarily in the first half of the study period.
- **Total resource use/impact:** : Wheat decreased total land use (-33%), and correspondingly decreased total soil erosion (-57%), irrigation water applied (-12%), energy use (-26%), and greenhouse gas emissions (-17%).

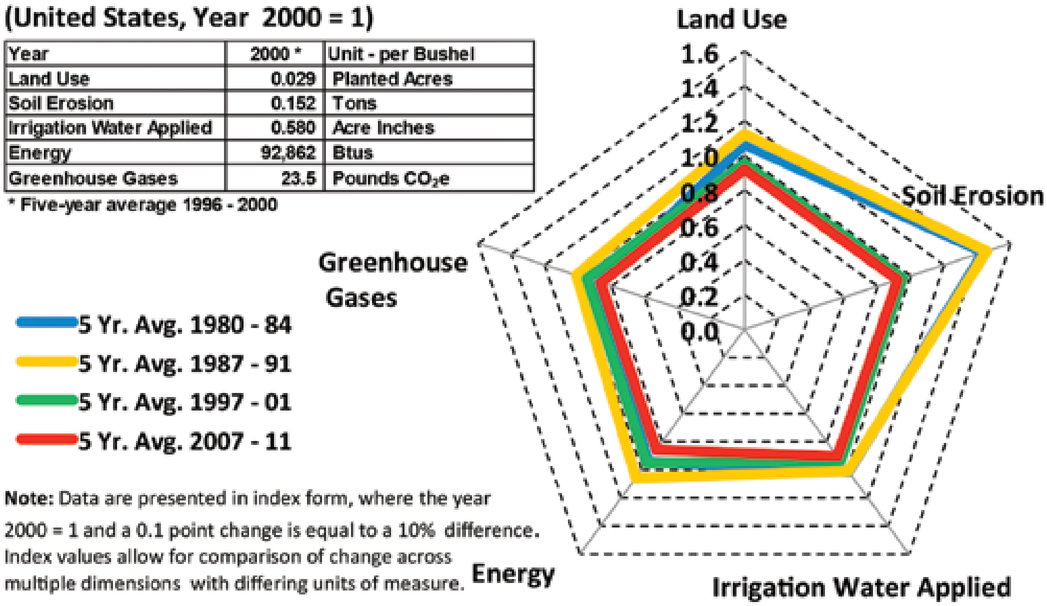
Please note: wheat use/impact for soil, energy, irrigation water applied and greenhouse gas emissions are allocated between wheat and straw using an economic allocation method, with 96.6 percent of use and resource impact values being attributed to wheat and 3.4 percent to wheat straw based on 2005-2009 economic data (land use acreage is not allocated). Values for wheat may be converted to values representing that required to produce both economic yield components, wheat and straw, by multiplying wheat values by 1.034.

Summary trends for specific indicators are provided in **Figure 1.81** and **Table 1.6** and in the text 5below. **Figures 1.82 through 1.96** demonstrate linear trends over the full study period for total, per acre, and per unit of production resource use/impacts. Average percent change values reported for the full study period are based on a least squares trend analyses from 1980-2011; significant variations from these average trends are noted below.

Index of Per Bushel Resource Impacts to Produce Wheat (United States, Year 2000 = 1)

Year	2000 *	Unit - per Bushel
Land Use	0.029	Planted Acres
Soil Erosion	0.152	Tons
Irrigation Water Applied	0.580	Acre Inches
Energy	92,862	Btus
Greenhouse Gases	23.5	Pounds CO_2e

* Five-year average 1996 - 2000



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

Figure 1.81 Index of Per Bushel Resource Impacts to Produce Wheat, United States, 1980-2011

Table 1.6 Wheat Summary of Results

Wheat Summary of Results: Trends in U.S. Production, Resource Use / Impact, 1980-2011				
Resource Area	**Indicator**	**Percent Change* 1980-2011**		
		Trend Direction	**Entire Period**	**Compound Annual**
Crop Yield	Total Production	↓	(16)	(0.6)
	Bushels per Acre	↑	25	0.7
Land Use	Total Planted Acres	↓	(33)	(1.3)
	Acres per Bushel	↓	(18)	(0.7)
Soil Erosion	Total Tons	↓	(57)	(2.7)
	Tons per Acre	↓	(34)	(1.3)
	Tons per Bushel	↓	(47)	(2.1)
Irrigation Water Applied	Total Volume	↓	(12)	(0.4)
	Volume per Irrigated Acre	↑	6	0.2
	Volume per Bushel	↓	(12)	(0.4)
Energy Use	Total Btu	↓	(26)	(1.0)
	Btu per Acre	↑	9	0.3
	Btu per Bushel	↓	(12)	(0.4)
GHG Emissions (CO_2 Equivalents)	Total Pounds	↓	(17)	(0.6)
	Pounds per Acre	↑	21	0.6
	Pounds per Bushel	↓	(2)	(0.1)

*Percent change results are based on a least squares trends analyses from 1980 - 2011

Sources: Calculations are based on a number of data sources: 1. USDA, NASS, Census of Agriculture, Farm and Ranch Irrigation Survey, http://www.agcensus.usda.gov/Publications/index.php 2. USDA, Economic Research Service (ERS), Agricultural Resource Management Survey (ARMS) http://www.ers.usda.gov/Briefing/ARMS/Access.htm 3. USDA, National Resources Conservation Service (NRCS), National Resrouce Inventory (NRI) Reports http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri

Total Production and Yield (Wheat)

Total production decreased for wheat while yield increased over the study period. Total production of wheat decreased by 16 percent, or 0.6 percent compound annually; 2.0 billion bushels of wheat were produced in 2011 as compared with 2.3 billion bushels in 1980. Planted area yield (bushels per planted acre) increased 25 percent over the study period, or 0.7 percent compound annually; average planted yield in 2011 was 36.8 bushels per planted acre as compared with 29.5 bushels per planted acre in 1980. Harvested acre yield in 2011 was 43.7 bushels per acre. Wheat research over the study period has focused on quality and milling traits more so than on yield.

Land Use (Wheat)

Total land use and land use per bushel decreased for wheat over the study period. Total planted acreage of wheat decreased by 33 percent, or 1.3 percent compound annually; 54.4 million acres of wheat were planted in 2011 as compared with 80.8 million acres in 1980. Harvested acreage of wheat was 45.7 million acres in 2011. Over the study period, the land use "efficiency" metric (acres per bushel) improved (decreased) by 18 percent, or 0.7 percent compound annually.

See **Figures 1.82, 1.83 and 1.84** for more detail regarding the annual land use, production, and yield values.

Soil Erosion (Wheat)

Soil erosion for wheat improved for all measures. Total tons of soil erosion for wheat decreased 57 percent over the study period, or 2.7 percent compound annually, corresponding with a decrease in total planted acreage; total soil erosion was 291 million tons in 2011 compared with 585 tons in 1980. In absolute terms (not relative to a tolerance rate or T), per acre soil erosion decreased 34 percent (1.3 percent compound annually) from more than 7 tons per acre in 1980 to 5.35 tons per acre in 2011. (Note: Tolerable (T) soil loss levels vary by soil type across the country but range from 3.0 to 4.9 tons per acre per year – with a simple average of 4.3 tons per acre). Tons per bushel decreased 47 percent (2.1 percent compound annually).

While the average trend since 1980 shows significant improvement per acre soil erosion, these improvements occurred primarily before the mid-1990s. Adoption of conservation tillage practices for wheat has been lower than for other crops, however these and other practices – including the Conservation Reserve Program, which removed significant proportions of highly erodible wheat land from production – have helped to drive improvement on a per acre and per bushel basis.

See **Figures 1.85, 1.86 and 1.87** for more detail regarding the annual soil erosion values.

Irrigation Water Applied (Wheat)

Irrigation water applied per bushel and total irrigation water applied decreased over the study period while irrigation water per acre increased for wheat. Wheat improved (decreased) its volume per incremental bushel produced as a result of irrigation by 12 percent (0.4 percent compound annually). Wheat increased its volume per irrigated acre (6 percent, 0.2 percent compound annually); the average acre inches applied per irrigated acre was 16.8 acre inches in 2011. Total irrigation water applied for wheat improved (decreased) 12 percent (0.4 percent compound annually) over the study period; total irrigation water applied for wheat was 59.4 million acre inches in 2011.

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 5 percent of wheat acreage was irrigated in 2011; a majority of irrigated wheat occurs in the Pacific Northwest.

See **Figures 1.88, 1.89 and 1.90** for more detail regarding the annual irrigation water applied values.

Energy Use (Wheat)

Per bushel and total energy use for wheat improved while per acre energy use increased. Energy use per bushel of wheat production improved (decreased) 12 percent (0.4 percent compound annually) over the study period, corresponding primarily with productivity gains; energy use per bushel was approximately 81,500 Btu per bushel in 2011 compared with 95,400 Btu per bushel in 1980. Energy use per acre increased by 9 percent (0.3 percent compound annually), from 2.8 million Btu per acre in 1980 to 3.0 million Btu per acre in 2011. Total energy use for wheat production decreased 26 percent (1.0 percent compound annually), corresponding with a decrease in total acreage; total energy use for wheat was approximately 163 trillion Btu in 2011, compared to 227 trillion Btu in 1980.

See **Figures 1.91, 1.92 and 1.93** for more detail regarding the annual energy use values.

Greenhouse Gas Emissions (Wheat)

Greenhouse gas emissions per bushel decreased slightly and total emissions decreased over the study period while emissions per acre increased for wheat. Per bushel greenhouse gas emissions for wheat improved (decreased) 2 percent (0.1 percent compound annually) over the study period, corresponding primarily with productivity gains; per bushel emissions were approximately 21.2 pounds of CO2e per bushel in 2011 compared with 22.1 pounds of CO2e per bushel in 1980. Emissions per acre increased by 21percent (0.6 percent compound annually), from 651 pounds of CO2e per acre in 1980 to 778 pounds of CO2e per acre in 2011. Total emissions decreased 17 percent (0.6 percent compound annually), corresponding with the decrease in total planted acreage; total emissions were approximately 42.3 billion pounds of CO2e in 2011, compared with 52.6 billion pounds CO2e in 1980.

See **Figures Figures 1.94, 1.95 and 1.96** for more detail regarding the annual greenhouse gas emissions values.

Please note, in the following graphs, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient will have the units of the indicators, e.g., tons of soil erosion per bushel per year. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

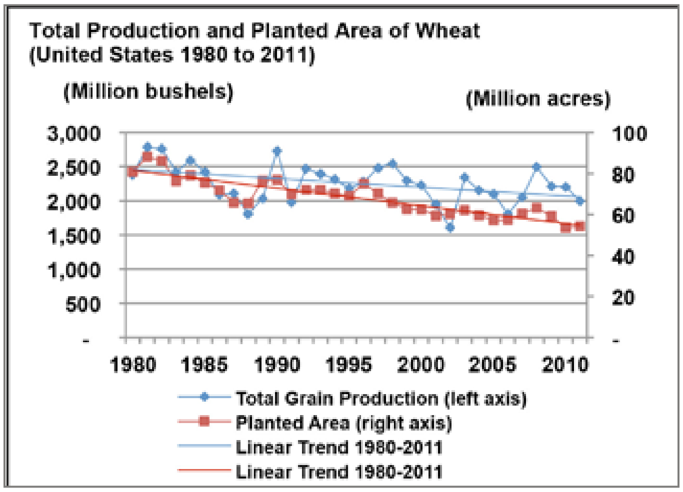


Figure 1.82 Total Production and Planted Area of Wheat, U.S. 1980 to 2011

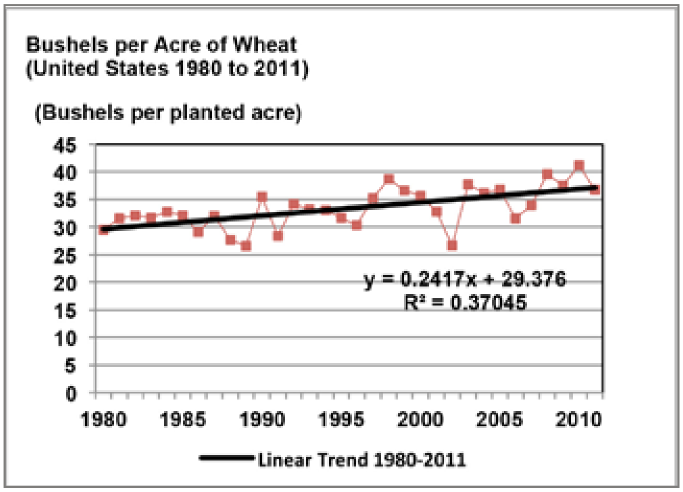


Figure 1.83 Bushels per Planted Acre of Wheat, U.S. 1980 to 2011

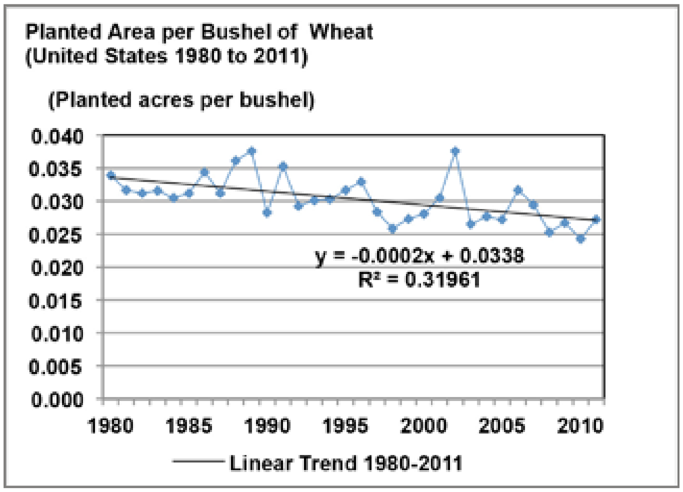


Figure 1.84 Planted Area per Bushel of Wheat, U.S. 1980 to 2011

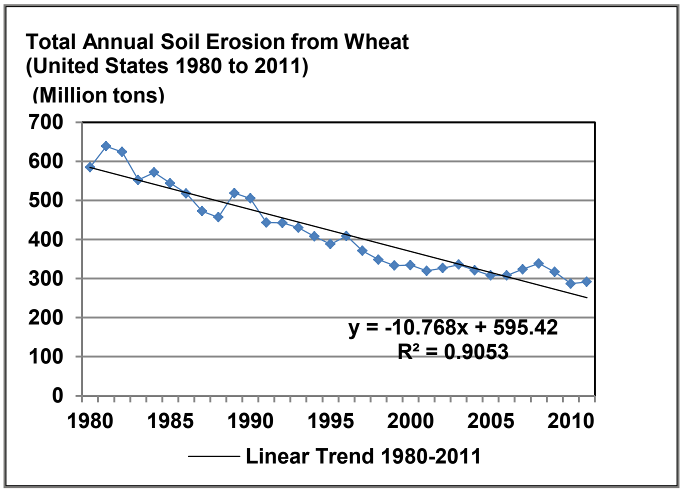


Figure 1.85 Total Annual Soil Erosion from Wheat, U.S. 1980 to 2011

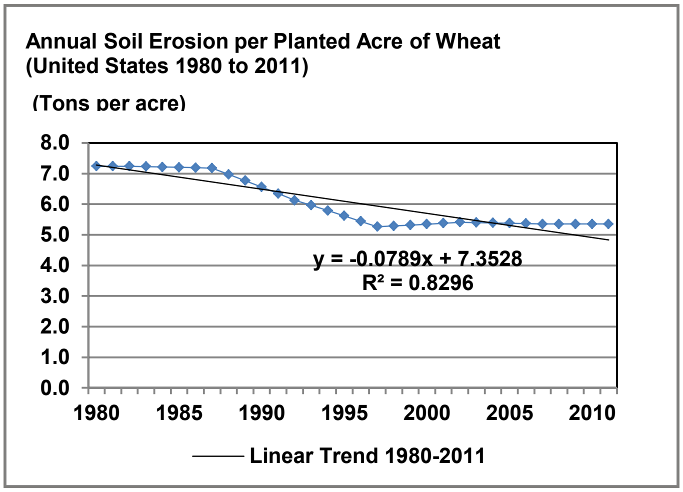


Figure 1.86 Annual Soil Erosion per Planted Acre of Wheat, U.S. 1980 to 2011

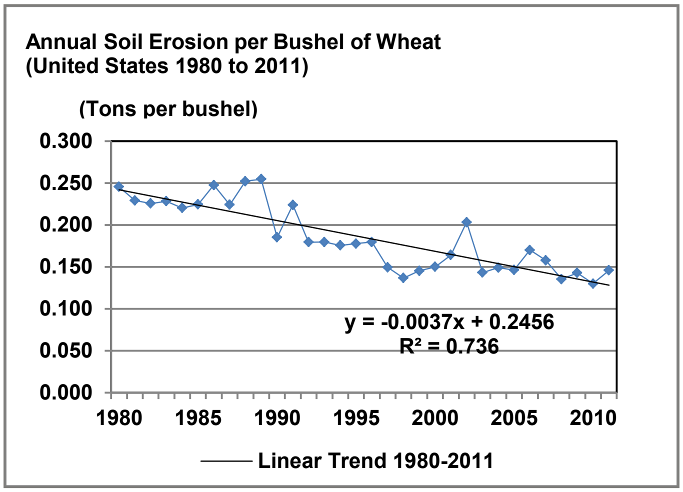


Figure 1.87 Annual Soil Erosion per Bushel of Wheat, U.S. 1980 to 2011

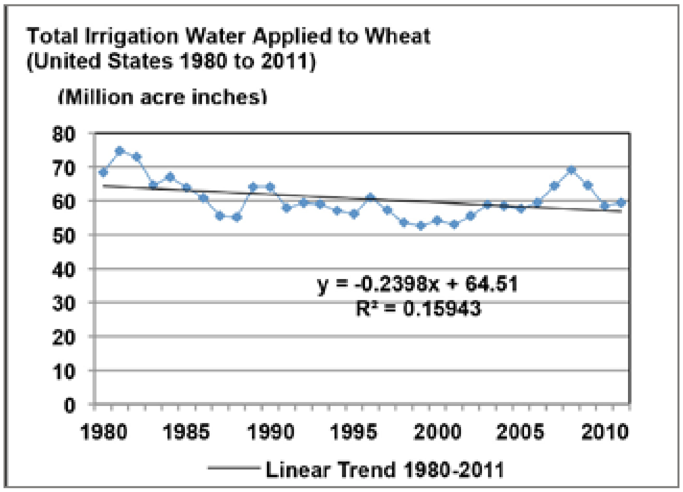


Figure 1.88 Total Irrigation Water Applied to Wheat, U.S. 1980 to 2011

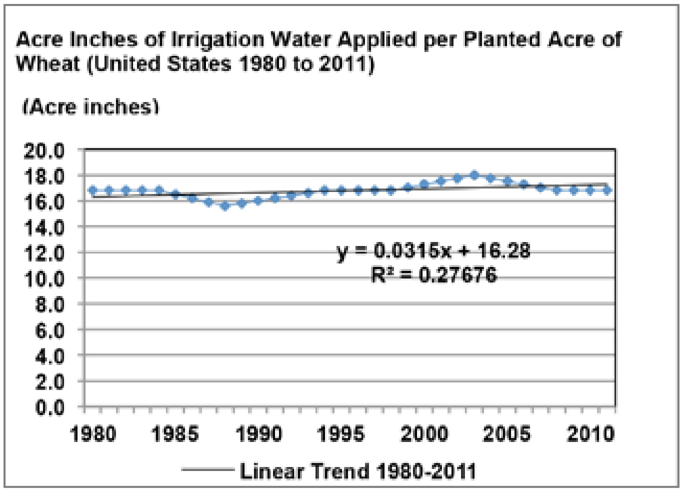


Figure 1.89 Acre Inches of Irrigation Water Applied per Planted Acre of Wheat, U.S. 1980 to 2011

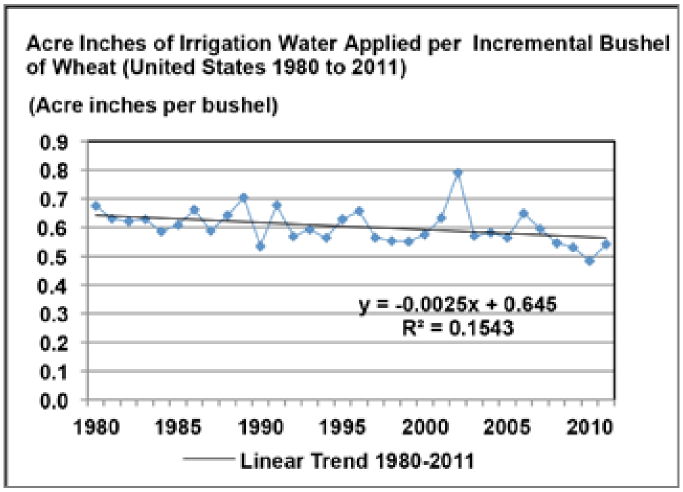


Figure 1.90 Acre Inches of Irrigation Water Applied per Incremental Bushel of Wheat, U.S. 1980 to 2011

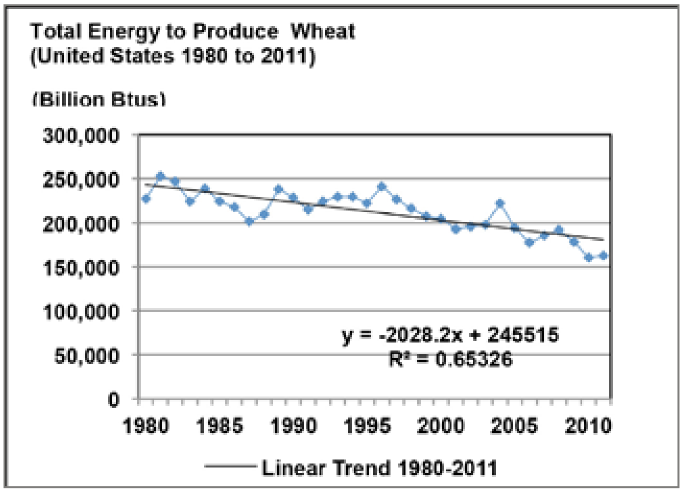


Figure 1.91 Total Energy to Produce Wheat, U.S. 1980 to 2011

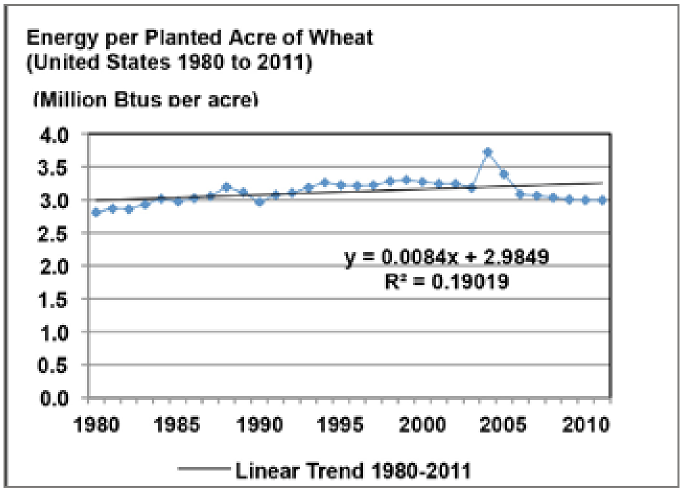


Figure 1.92 Energy per Planted Acre of Wheat, U.S. 1980 to 2011

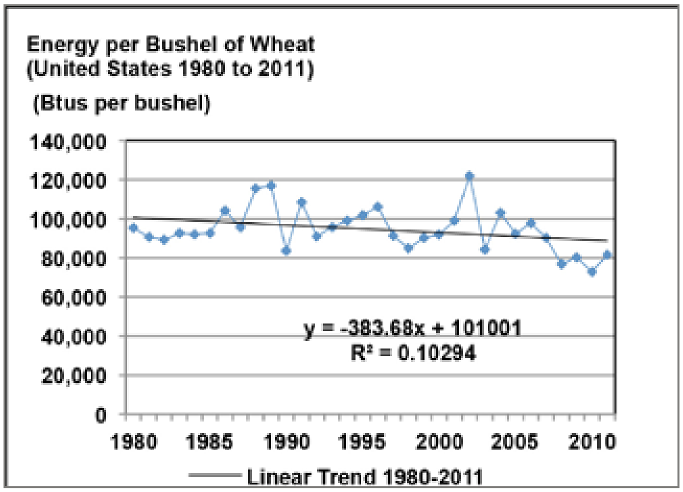


Figure 1.93 Energy per Bushel of Wheat, U.S. 1980 to 2011

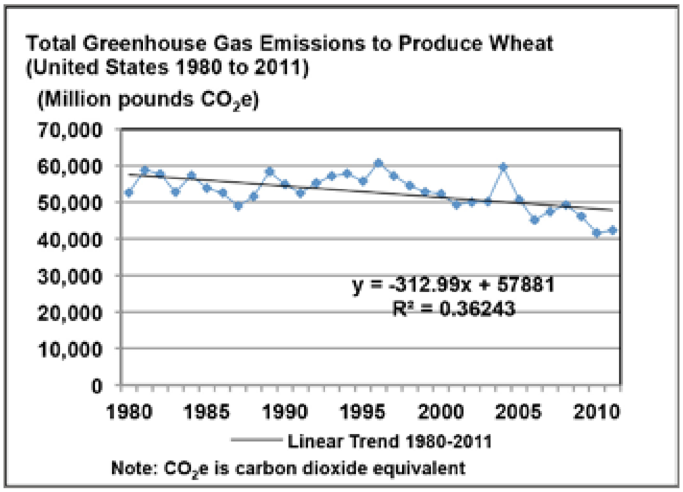


Figure 1.94 Total Greenhouse Gas Emissions to Produce Wheat, U.S. 1980 to 2011

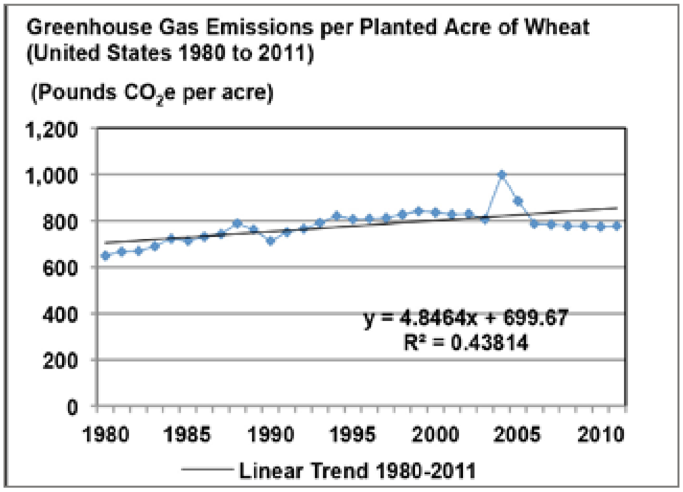


Figure 1.95 Greenhouse Gas Emissions per Planted Acre of Wheat, U.S. 1980 to 2011

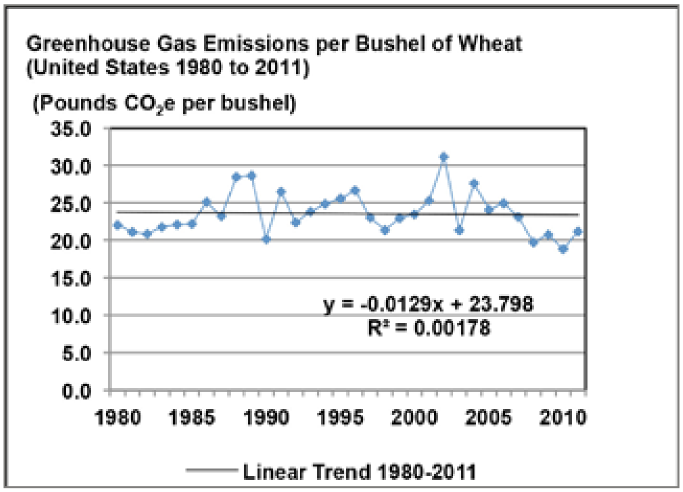


Figure 1.96 Greenhouse Gas Emissions per Bushel of Wheat, U.S. 1980 to 2011

4. Discussion and Conclusions

This report does not define a benchmark level for sustainability for environmental indicators. Rather, it explores broad-scale, commodity-level progress over time related to the major challenge facing agriculture in the twenty-first century: increasing demand and limited resources. By exploring three different metrics for each indicator – total use/impact, per acre, and per unit of production – the report offers an opportunity to better understand and contextualize outcomes of relevance to the challenge of increasing production and improving environmental outcomes. As described in the introduction to the results section, each data format provides unique perspective and also bears specific caveats.

As demonstrated by the results, over the study period of more than three decades, all six crops demonstrated progress in resource use/impact per unit of production on all five environmental indicators – an indication of continuous improvement toward producing crops more efficiently, with less resource use and impacts per unit of production. Improvements in efficiency were driven, at least in part, by improvements in yield for all crops. However, due in part to overall increases in production for five of the six crops (excluding wheat) and increases in total land use for four of the six crops (excluding potato and wheat), total resource use/impact increased for many crops on many indicators. These trends of increased efficiency, but also increased total resource use suggest that a challenge for the future will be to continue efficiency improvements such that overall resource limits (e.g., land, water, and energy) are not reached.

In general it should also be noted that while national trends may show improvement, specific local examples of continued challenges cannot be overlooked. Conversely, some national trends may show overall increases in total uses or decreases for efficiencies for a particular crop even while success stories may be occurring at more local levels. Further exploration of trends at more regional or local levels are outside the scope of this report and although they are important considerations for future study, the results for these types of analyses are not provided.

By advancing an outcomes and science-based approach to understanding and measuring sustainability indicators, this report represents a starting place for discussion and further research. Specific opportunities for continued refinement and extension of the work presented here include:

Expansion of indicators. The indicators presented in this report do not represent the full suite of sustainability indicators for agriculture. Expansion of the current indicator set to include additional crops as well as additional environmental indicators may occur given available methods and datasets. In particular, Field to Market continues to explore development of metrics for water quality and biodiversity. The next chapter of this report provides an analysis of national scale social and economic indicators for agricultural sustainability since social and economic dimensions are fundamental to all conversations regarding sustainability.

Refinement of methods and data. On a technical level, the updated approaches and results for the environmental indicators presented in this report represent continued and important progress towards evaluating agricultural sustainability and tracking progress over time. Refinements in methodology as compared with Field to Market's 2009 environmental indicators approach add robustness to results, and an expansion of data analyzed provides a longer-term and up-to-date analysis of trends for major commodity crops. Current methodology and results may be modified and improved as research, time and better and/or more recent data allow. Capacity to continue and enhance these kinds of analyses is dependent on the availability of the public data sources upon which it heavily relies. Public, national level datasets provide a transparent, accessible, and fundamental means of understanding sustainability trends. Examples of data and research that could improve future analyses include soil erosion data utilizing RUSLE2 rather than the USLE model, data for the quantification of fuel efficiency and emissions over time associated with equipment technology changes, and data and methods to better account for sequestration of carbon under various tillage systems, and improved data and coefficients for estimating rice methane emissions. 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 such as alfalfa with smaller crop acreages.

Scaling of approaches. Downscaled analyses may require more sophisticated methodologies and datasets to allow for higher resolution, better interpretation of trends at local levels, and better understanding of how specific decisions affect specific resources and geographies. This report utilizes methods that strive for high scientific sophistication while also recognizing the limits of working with public data and at a broad-scale. More locally-scaled analyses may utilize and even require methods not feasible and data not available at the national scale, as local decisions will require more specific information to inform management and decision-making.

Exploration of impacts. Further analyses at all scales are needed to better understand the total impacts of crop production. For example, within our environmental indicators, efficiency and total use trends at the national scale do not capture the specific challenges associated with resource limitations and impact, including those at smaller scales. While many national trends show improvement for particular crops, whether for efficiency measures or total resource, overall national or even global resource limitations cannot be overlooked, nor can specific local examples of continued challenges. For example, sustainability can be impacted by nationally and globally available cropland and energy sources, as well as by groundwater availability for a particular regional or local aquifer. Conversely, some national trends may show overall increases in total uses for a particular crop even while success stories may be occurring at more local levels or may be occurring in consideration of all crops grown in a particular area.

Aggregation of results across all crops. Further analyses are needed to better understand the cumulative or aggregate impacts of all crop production. While crop-by-crop analyses provide important information for commodity sectors and supply chains, aggregation of data for all crops may provide further insight into directional changes in total uses. For example, increases or decreases in resource use for a single crop may actually be offset by decreases or increases for another crop, and aggregate results may in some cases be directionally different than by-crop results, both at the national and local scale. Aggregate total resource uses may also vary in direction at the local scale as compared to national scale; for example, due to land use change either away from agricultural production (e.g., conversion to urban land) or into production (e.g., release of Conservation Reserve Program land back into production). Similarly, for socioeconomic indicators, further analyses at additional scales and for the aggregate of agricultural production are needed, as are enhanced measures of impact on the farmer and farm community.

Evaluation of context and drivers. Further analyses are also needed to better understand both the context and drivers underlying the trends reported here. Context and drivers can include conditions both internal and external to agricultural systems – such as resource limitations and conditions (at a variety of scales), individual farmer choices, availability of new science and technology, profitability needs, supply chain and economic conditions, price signals, consumer behaviors, demographic changes, governance, and policy, including Farm Bill policies and programs such as the Conservation Reserve Program and ethanol mandates associated with energy policies. Because agriculture is an incredibly complex system and analysis of context and drivers equally complex, Field to Market does not attempt in this report to analyze nor speculate on them unless they are explicitly evident in the datasets used to build the metrics themselves.

Examination of recent trends versus historical trends. Further analyses are also particularly needed to better understand the most recent trends, drivers, and contexts for sustainability. This report highlights results in summary form – for example, percent change over the full 30-year study period – and also includes data demonstrating the full time series of trend lines for each crop and indicator. There are many more stories to be further explored and explained within the data provided in this report, including and especially those for which more recent trends may represent accelerations, decelerations, or reversals of the overarching 30-year trend-lines. The longer time period provides important historical context; the most recent trends may signal important considerations for the future. In particular, the soil erosion metric for many crops demonstrates more recent slow-downs and in some cases reversals in progress.

Expansion to additional crops and geographies. Field to Market's primary focus is currently on commodity agricultural production in the United States; however, the Alliance seeks to inform efforts focused on other crops and geographies by facilitating information-sharing, coordination, and collaboration regarding methodologies and approaches. As an example, Field to Market's 2009 report was recently adapted for Canadian field crops.[91] Field to Market continues exploration of opportunities to leverage and adapt the current work to new contexts, both within and beyond the United States.

Connecting trends to individual grower education and action. Field to Market's analysis of broad-scale trends provides a mechanism to measure overall progress. Yet what moves the "needle" of sustainability outcomes at the broad scale are individual practices and outcomes at the field and farm scale. Complementing its efforts to analyze broad-scale trends, Field to Market has also developed the Fieldprint Calculator, a free, online educational and awareness tool that allows individual growers to analyze the outcomes of their own management practices at the field level and compare them to broader-scale benchmarks as well as to trends within their own peer or pilot groups (www.fieldtomarket.org). Field to Market is actively engaged in piloting these tools and methodologies with farmers to identify future improvements and understand the utility of these tools in informing management actions and driving continuous improvements.

[91] Serecon Management, for Pulse Canada, Canadian Canola Growers Association, Canadian Wheat Board, Ducks Unlimited, Flax Council of Canada, and General Mills. 2011. Application of Sustainable Agriculture Metrics to Selected Western Canadian Field Crops: Final Report. Edmonton, Alberta. http://www.pulsecanada.com/fieldtomarket

The above-recommended future investigations represent significant opportunities for which this report is intended as a starting place. Through this report and Field to Market's advancement of agricultural sustainability metrics and tools that quantify the impacts of cropping practices 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 hope and intent is that such approaches will ultimately inform mechanisms to promote continuous improvements at the field level that aggregate, 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.

Part II: Socioeconomic Indicators Report

1. Introduction

Field to Market, The Keystone Alliance for Sustainable Agriculture is a collaborative stakeholder group involving producers, agribusinesses, food and retail companies, conservation and non-profit organizations, and university and agency partners working together to promote, define and measure the sustainability of food and fiber production.

Consistent with the Brundtland Report's definition of sustainable development, 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

It is within this context that Field to Market is developing and refining metrics to measure the environmental and socioeconomic outcomes of commodity agriculture in the United States. These metrics will facilitate quantification and identification of key impact areas and trends over time, foster productive industry-wide dialogue and promote continuous improvement along the path toward sustainability.

This section, Part II: Socioeconomic Indicators, represents a new set of indicators as compared with the original 2009 Field to Market report. Social and economic sustainability are critical pillars of total sustainability, and Field to Market is pleased to take a first step, through this report, in introducing analyses for these indicators at the national and regional scale. While global demand, production, and sustainability trends are influenced by a myriad of complex drivers and conditions at a variety of scales, Field to Market's exploration of sustainability metrics has focused on United States agriculture and the science-based measurement of outcomes associated with the production of commodity crops. This focus provides important insights for sustainability of U.S. commodities, which represent a significant proportion of the cropland in the United States and are often associated with complex supply chains that require innovative approaches to measurement and data sharing. This current focus provides a starting point for further analysis and for the development of methodologies and approaches that could be further adapted and applied to other contexts.

Crop production is a complex operation and depends on environmental, political, and socioeconomic factors. Crop production efficiency and effectiveness evolves with the increased knowledge and sophistication of the agricultural community. Training, experience, and knowledge combined with favorable macro- and micro-economic climates can provide incremental improvements and/or innovation in farming techniques and technologies.

In order to address the social and economic concerns of sustainable agriculture, this section, Socioeconomic Indicators, identifies and discusses a limited number of social and economic indicators that contribute to the success and wellbeing of the farmer and farming community.

This report provides the national perspective on the annual changes in the socioeconomics of production agriculture, with some regional perspectives where possible and applicable, to describe a picture of the economic and social implications of producing commodity crops. This discussion of socioeconomic characteristics of sustainable land management includes the structure and financial status and performance of U.S. farm operators, their households, and farm businesses. Some examples of this structure include demographics, labor, various financial metrics, injury, productivity, and education levels.

Consistent with the 2009 Field to Market report and with the criteria for environmental indicators, criteria for development and inclusion of Field to Market socioeconomic indicators in the 2012 report are as follows:

1. **National scale** – Analyzes national level sustainability performance of crop production. National scale indicators can provide perspective and prompt industry-wide dialogue that is ultimately relevant to more localized investigations and efforts.
2. **Trends over time** – Metrics that allow comparison of trends over time rather than a static snapshot of farm activity.
3. **Science-based** – Utilizes best available science and transparent methodologies.
4. **Outcomes-based** – Provides an inclusive mechanism for considering the impacts and sustainability of diverse agricultural products and practices.
5. **Public dataset availability** – Utilizes publicly available data. Public, national-level datasets provide a transparent, accessible, and fundamental means to understand sustainability trends.
6. **On-farm** –Focuses on outcomes resulting from agricultural production within the farm-gate.
7. **Grower direct control** – Focuses on impacts over which a producer has direct influence through his or her management practice choices.

Numerous domestic and international initiatives have investigated and developed outcomes-based socioeconomic metrics for agriculture. Field to Market evaluated these methodologies and data for their consistency with the criteria described above. Among those reviewed were: Australia's Natural Heritage Trust, Australian Bureau for Agricultural and Resource Economics (ABARE),[92] Sustainable Agriculture Initiative (SAI) Platform Dairy Working Group's Principles & Practices for the Sustainable Dairy Farming,[93] UNEP's Guidelines for Social Life Cycle Assessment of Products,[94] the Response-Inducing Sustainability Evaluation (RISE) model, and the USDA's Economic Research Service (ERS) and Agricultural Resource Management Survey (ARMS).[95]

[92] ABARE. 2005. Signposts for Australian Agriculture: A framework for developing economic and social indicators, October 2005. Canberra: National Land & Water Resources Audit.

[93] SAI Platform Dairy Working Group. 2009. Principles & Practices for Sustainable Dairy Farming. Sustainable Agriculture Institute Platform. http://www.saiplatform.org/library

[94] UNEP. 2009. Guidelines for Social Lifecycle Assessment of Products. United Nations Environment Programme. http://www.unep.fr/scp/publications/details.asp?id=DTI/1164/PA

[95] USDA ERS. 2011. Agricultural Resources Management Survey. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://www.ers.usda.gov/briefing/ARMS

[96] ABARE. 2005. Signposts for Australian Agriculture: A framework for developing economic and social indicators, October 2005. Canberra: National Land & Water Resources Audit.

Australia's Natural Heritage Trust's The National Land and Water Resources Audit's project Signposts for Australian Agriculture: A Framework For Developing Economic and Social Indicators, October 2005, defined eight criteria for identifying indicators (defined below). According to the report, indicators should be:

1. Related to identifiable policies or actions.
2. Directly related to the impacts of agriculture on outcomes.
3. Influences of factors other than agriculture on the indicator should be minimal.
4. Unambiguous, clearly indicating movement toward (or away) from desirable outcomes.
5. Able to be interpreted in context of appropriate scales and coverage.
6. Not be difficult or costly to measure using data of appropriate quality, availability and reliability.
7. Sensitive to measuring change across appropriate time dimensions and should be able to monitor change across locations and industries.
8. Amenable to predicting outcomes.

This study also discusses the concern for ambiguous interpretation of data when selecting socioeconomic indicators where data are liable to more than one interpretation, explanation or meaning. For example, the number of farm accidents can be used as a direct measure of agriculture's contribution to a community's health, whereas the number of visits to a doctor cannot be directly ascribed to agriculture. Indicators should also be unambiguous in defining whether outcomes are desirable at different scales. For example, a decline in local population may not be desirable at a regional level, but when viewed at a state or national level it might reflect a reallocation to employment opportunities elsewhere.

The RISE model incorporates social security, working conditions, local economy and economic stability and efficiency along with natural resources and management indicators into its output to demonstrate opportunities for improvement.

The indicators and their parameters were selected in a way to allow the farm manager (or other relevant entities) to exert an influence over their own particular sustainability situation and development.[97]

ERS data and ARMS survey data were consulted to understand the types of data that are collected regularly for the agronomic sector in the U.S. and are thus deemed relevant to socioeconomic indicators. Social facets include poverty status, access to health care including health insurance coverage, workplace fatalities, and labor allocations of farm households to farm and off-farm work. Economic facets include the income and economic well-being of the households of the principal operators of family farms, contribution to the national economy, and the economics of production practices used across commodity enterprises.

For this study, data has been retrieved and assembled across five primary crops in the United States:

1. Corn
2. Cotton
3. Rice
4. Soybeans
5. Wheat

These crops were selected for their consistency with the environmental indicators report. Together, the production of these crops has comprised a vast majority of the acres of agricultural cropland use in the United States for the past several decades.

Table 2.1 lists the components considered and explored in creating a socioeconomic index. Indicators included in the report are discussed in detail, and information on data and methodologies are accompanied by relevant data and analysis. Indicators that were explored but not included in the report for various reasons are discussed but no data are shown. Please see Chapter 2 Data and Methods for further explanation concerning reasons for not providing data on indicators explored but not included.

[97] University of Applied Sciences Swiss College of Agriculture. 2009. RISE Model. Zolikofen, Switzerland.

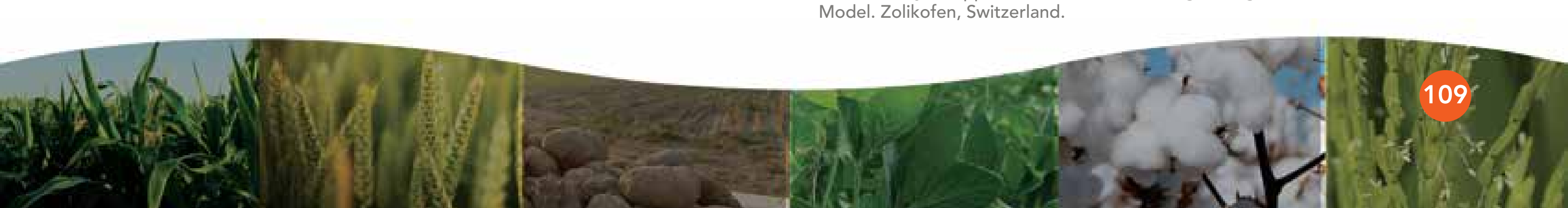


Table 2.1 Socioeconomic Indicators Included and Explored

Socioeconomic Indicators Included			
Type	**Indicator**	**National**	**Regional/State**
Economic	Debt/Asset Ratio	X	
	Return Above Variable Costs	X	
	GDP/Tax Base Contribution	X	X
Social	Non Fatality Illness and Injury	X	
	Fatalities	X	
	Labor Hours	X	X

Socioeconomic Indicators Explored But Not Included	
Type	**Indicator**
Economic	Real Gross Revenue per Acre
	Cropland Value
	Total Factor Productivity
	Cash Flow
	Input Costs
	Costs of Funds
	Household income
Social	Farmer Education
	Community Education
	Succession Planning
	Land Ownership and Tenure
	Poverty Rate
	Health Care Insurance
	Farm Labor Practices/Child Labor Practices
	Incidence Levels of Food-Borne Illness
	Biosecurity Protection Against Transmission of Zoonotic Diseases

X=Geographic representation

2. Data and Methods

2.1. Data and Methods Overview

The benchmark data for this report comes from the USDA and is an outcome of its Farm Cost and Returns data and the ARMS (Agricultural Resource Management Survey) dataset. Other higher frequency, monthly, data are collected for the prices paid for farm inputs such as fuel, seed, fertilizer, etc. These monthly data are published in the Agricultural Prices report from NASS (National Agricultural Statistics Service). 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. Major field and row crops are surveyed approximately every 5 years. Data for prices paid by farmers for inputs to their production process are collected annually and published in the Agricultural Prices report. The most recent ARMS surveys for the crops we cover are wheat (2009), cotton (2007), soybeans (2006), rice (2007), and corn (2010).[98]

ERS U.S. Farm Resource Regions

In order to identify regional patterns in U.S. farming that might further the understanding of differences in financial performance of farms and the economic well-being of farm households, the USDA's Economic Research Service (ERS) constructed Farm Resource Regions that depict geographic specialization in production of U.S. farm commodities. In **Figure 2.1**, regions are defined by like farming characteristics rather than state lines.[99]

National, regional and state data have been considered where possible. Definitions of farming regions are described by the ERS U.S. Farm Resource Regions (see methodology) where regions are defined by like farming characteristics rather than state groupings. Varying time periods were selected such that the data used for a particular indicator are reported in a consistent format.

The data analyzed in this report have been retrieved from numerous sources – all are within the public domain. Data and methods for each socioeconomic indicator are further explained below. Data analysis and summary have been completed by IHS Global Insight, an economic, financial analysis, forecasting and consulting firm with more than 40 years of experience.

98 USDA ERS. 2011. Commodity Costs and Returns. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://www.ers.usda.gov/Data/CostsAndReturns

99 USDA ERS. 2011. U.S. Farm Resource Regions. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://www.ers.usda.gov/Briefing/ARMS/ResourceRegions/ResourceRegions.htm

100 USDA NASS. 2008. Crop Values 2007 Summary. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. http://www.usda.gov/nass/PUBS/TODAYRPT/cpvl0208.pdf

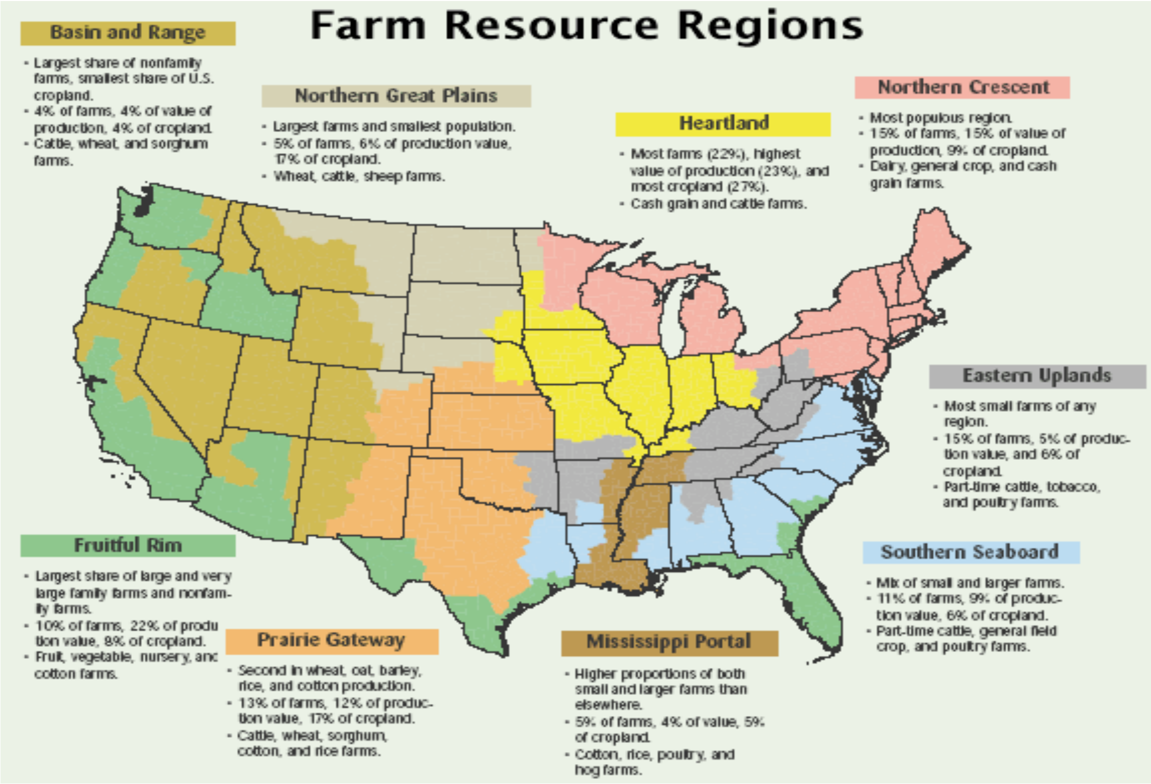


Figure 2.1 USDA Farm Resource Regions

For this study, data has been retrieved and assembled across five primary crops in the United States:

	Crop	Yield Unit	Description
1	Corn	bu.	Bushel, 56lbs. of corn grain per bushel
2	Cotton	lb. of lint	Pounds (lbs.) of lint
3	Rice	cwt	Hundred weight, (100 lbs.)
4	Soybeans	bu.	Bushel, 60 lbs. of soybean seed per bushel
5	Wheat	bu.	Bushel, 60 lbs. of wheat grain per bushel

Together, the production of these five crops plus potatoes has comprised approximately 73 percent of the acres of agricultural cropland use in the United States for the past several decades. In 2011, the six crops comprised 73.9 percent of the 293.4 million acres of U.S. agricultural crops harvested and had combined crop value of $119 billion.[100] It is our intention that the methods used could be applied to a full range of technology choices and to other crops produced in the United States or elsewhere assuming sufficient data and, perhaps, with some modification. A comprehensive set of metrics were considered and six were identified as relevant and possible according to the criteria discussed in the introduction. The complete set of metrics considered is described in Table 2.1.

In selecting resource indicators, the group has chosen to focus on six important indicator areas. The six areas are:

1. Debt/Asset Ratio
2. Returns Above Variable Costs
3. GDP
4. Non-Fatality Illness and Injury
5. Fatalities
6. Labor Hours

Data Concerns for Metrics Investigated but Not Included

The importance and relevance of metrics that were considered but not included are discussed in the section 4.0 Socioeconomics Metrics Investigated But Not Included. The main issues contributing to the exclusion of the investigated metrics are definitional or directional ambiguity, sporadic data, and/or relevance to commodity crop farming. In many instances, available data are not crop specific or the metric is not sufficiently within direct control of the farm operator and meaningful conclusions cannot be derived. While many indicators are not solely within the control of a grower to influence, our intent is to focus on those that can be attributable in some significant way to actions taken by the farmer. In some instances, data were deemed inappropriate for this study due to categorization by geography rather than crop type. In addition, USDA ARMS classifies farm types as those having a value of production of 50% or more from a particular activity and therefore may skew data by crop type. Finally, cotton is typically reported with tobacco and peanuts data, and cannot be broken out by specific crop type.

2.2 Debt/Asset Ratio

The debt to asset ratio indicates what portion of the farm's assets is being financed through debt. Farms with high ratios are highly leveraged and may be at risk for foreclosure if creditors demand repayment of debt.

Data for this indicator were provided by the USDA ERS Farm Business and Household Survey Data's Farm Business Financial Ratio Report of Farm Finances Survey for all farms from 1996 to 2011.[101] Rather than specific crop data, general cash grains were used due to the ERS parameters of data collection. ERS defines a farm as being crop specific if 50% of its income is received from a specific crop.[102] As most commodity crop farms plant a differing ratio of crops each year, the data do not provide specific enough data pertaining to each crop to provide meaningful results.

101 USDA ERS. 2011. Agricultural Resources Management Survey. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://www.ers.usda.gov/briefing/ARMS

102 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.

2.3 Returns Above Variable Costs

Returns above variable costs assist in gauging the potential profitability of a farming operation and helps growers evaluate alternative strategies for making the most out of their land, capital and labor. Variable costs are the out-of-pocket cash expenses paid for inputs unique to the commodity being produced. Variable expenses depend on production practices and on quantities and prices of inputs. These include inputs such as seed, fertilizer, feed, chemicals, and hired labor. These costs do not include land costs such as rent or taxes. Fixed costs such as equipment were not considered in this report due to accounting methodology for various costs including depreciation that may not accurately represent true farm cost structures and actual depreciation levels.

The benchmark data for these figures come from USDA and are an outcome of its Farm Cost and Returns data and the ARMs dataset (Agricultural Resource Management Survey).[103] Other higher frequency, monthly, data are collected for the prices paid for farm inputs such as fuel, seed, fertilizer, etc. These monthly data are published in the Agricultural Prices report from the National Agricultural Statistics Service, NASS.[104] 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. Major field and row crops are surveyed approximately every 5 years. Data for prices paid by farmers for inputs to their production process are collected annually and published in the Agricultural Prices report. The most recent ARMS surveys for the crops covered in this report are wheat (2009), cotton (2007), soybeans (2006), rice (2007), and corn (2010).

The measure we are presenting as an indication of net returns for producing crops above variable costs is calculated on a planted acre basis so if any abandonment occurs, it is amortized across the crop that was produced. As a starting point, gross income is calculated as the sum of the values of production from primary and secondary products (for example wheat grain and straw) plus any government payments that are provided that are dependent on the act of producing the crop (for example loan deficiency payments). While loan deficiency payments have significantly declined in recent years, they remain a factor in legacy USDA accounting principles. Payments that are made irrespective of whether or not a crop is planted (fixed payments) are not included.

[103] USDA ERS. 2011. 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

[104] USDA NASS. 2011. Agricultural Prices 2011. Washington, D.C.: United States Department of Agriculture, National Agricultural Statistics Service. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1002ERS%20Cost%20and%20Returns

From a cost perspective, all costs, such as fertilizer, seed, fuel, chemicals, repairs, paid labor and more, are included. Fixed costs such as land and land rental, equipment depreciation, and payments to management are not included. Variable costs are subtracted from gross income and the resulting number is deflated by the Consumer Price Index (CPI), providing a measure of returns above cost on an inflation-adjusted basis. The net-returns above variable cost for each crop are deflated by the consumer price index (CPI) so that the change over time in the resulting numbers is a representation of how well a crop farmer could provide for his or her family, i.e. inflation corrected income. The rationale for this approach is that net returns already have most of the farm expenses netted out such as fertilizer, fuel, chemicals, etc. and the result is representative of their income to be used for living expenses. Over time the concept is meant to reflect whether the returns from growing a certain crop are keeping up with inflation or not.

The Real Returns Above Variable Costs indicator normalizes data by using the year 2000 real dollars to adjust for inflation. Beyond the adjustment for inflation, the measure is presented as a 5 year moving average where, for example, the year 2000 value is the average of the years 1996 through 2000. The 5-year average is presented 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.

2.4 Agricultural Contribution to National and State GDP

GDP by state is the value added in production by the labor and capital located in a state. GDP for a state is derived as the sum of the gross domestic product by state originating in all industries in a state. In concept, an industry's GDP by state, referred to as its "value added," is equivalent to its gross output (sales or receipts and other operating income, commodity taxes, and inventory change) minus its intermediate inputs (consumption of goods and services purchased from other U.S. industries or imported). Thus, GDP by state is the state counterpart of the nation's gross domestic product.

GDP by state differs from national GDP for the following reasons: GDP by state excludes and national GDP includes the compensation of federal civilian and military personnel stationed abroad; government consumption of fixed capital for military structures located abroad; and military equipment. GDP by state and national GDP also have different revision schedules.

The U.S. Bureau of Economic Analysis (BEA) defines agriculture as including both crops and livestock and does not provide further data categorizations.[106]

[106] U.S. Department of Commerce BEA. (2011). 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

2.5 Non-Fatality Illness and Injury

Workplace safety is captured in data collected by the Bureau of Labor Statistics (BLS). Data for fatalities by industry classification are available from 1993 through 2010; data prior to 2008 are based on the 2002 National American Industry Classification System (NAICS) while data for 2008 through 2010 are based on the 2007 NAICS.[107] From the documentation the changes between the two classifications should not stop users from comparing data across years; the changes are relatively minor. Data on workplace fatalities are reported by industry for companies of all sizes including single employee workplaces.

Data for non-fatal injuries are also sourced from the BLS but have one significant difference: mandatory reporting of injury data starts with firms having more than 10 employees. In the case of farms this reporting threshold excludes the majority of all farms. At the national level the employee threshold excludes roughly 90% of all farms but does capture 57% of all farm labor. Distribution of this coverage is not uniform. For example, the portion of farms in California with greater than 10 employees is 25% and the share of their labor covered is 85%. While in Iowa the share of farms represented is 1% while the share of farm labor is about 26%.

Despite the lack of representation of small farms in the non-fatal injury data, we use the data as an indication of trends in the farm workplace. The data include statistics on the type of injury and cause of death but these data for agriculture were thinly populated and were not easy to draw conclusions from, particularly in the context of a time series analysis. The data for non-fatal injury were analyzed both in terms of incidence of one or more lost work days as well as an attempt to estimate the cumulative number of lost work days for the year.[108] Ultimately we are presenting the incidence of one or more lost work days as the data seemed to be highly variable when approximating the total days lost.[109]

The NAICS classifications allow for analysis of crop farms by specialization but these data also seemed to have areas of very thin recording if at all. For that reason we created a single category defined as all crop farms less those that grow vegetables, fruits and nuts, greenhouse crops, or horticultural specialties. 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 levels per 1000 employed or any measure of output. Human lives and significant injuries are not something that should be considered as a tradeoff to productivity or output. Any amount of injury or loss of life is too much and the target should be zero.

[107] U.S. Bureau of Labor Statistics. (2010). Washington, DC: United Sates Bureau of Labor Statistics. http://www.bls.gov/iif/oshwc/cfoi/cftb0243.pdf

[108] US Bureau of Labor. (2010). Number and percent distribution of nonfatal occupational injuries and illnesses involving days away from work by industry and number of days away from work, private industry, 2009. Washington, DC: United Sates Bureau of Labor. http://www.bls.gov/iif/oshwc/osh/case/ostb2511.pdf

[109] U.S. Bureau of Labor Statistics. (2011). Washington, D.C.: United States Department of Labor, Bureau of Labor Statistics. http://www.bls.gov/iif/oshwc/cfoi/cftb0243.pdf

2.6 Fatalities

Workplace safety is captured in data collected by the Bureau of Labor Statistics (BLS).[110] Data for fatalities by industry classification are available from 1993 through 2010; data prior to 2008 are based on the 2002 National American Industry Classification System (NAICS) while data for 2008 through 2010 are based on the 2007 NAICS. From the documentation the changes between the two classifications should not stop users from comparing data across years; the changes are relatively minor. Data on workplace fatalities are reported by industry for companies of all sizes including single employee workplaces.

The NAICS classifications allow for analysis of crop farms by specialization but these data also seemed to have areas of very thin recording if at all. For that reason we created a single category defined as all crop farms less those that grow vegetables, fruits and nuts, greenhouse crops, or horticultural specialties. 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 levels per 1000 employed or any measure of output. Human lives and significant injuries are not something that should be considered as a tradeoff to productivity or output, and any amount of injury or loss of life is too much and the target should be zero.

[110] U.S. Department of Labor BLS. (2011). Injuries, Illnesses, and Fatalities. Washington, D.C.: United States Department of Labor, Bureau of Labor Statistics. http://www.bls.gov/iif/oshsum.htm

2.7 Labor Hours

The data for labor hours were derived from the USDA Economic Research Service (ERS) Commodities Cost and Returns data.[111] The data are broken out by farm enterprise and consist of hired labor cost per acre and unpaid labor opportunity cost per acre from 1975 to 2009. Data were also used from the USDA National Agricultural Statistics Service (NASS) and include farm labor wage rate in each quarter from 1975 to 2009.

Labor hours per acre for each crop were derived from:

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

A 3-year centered moving average was used to smooth the influence of single data point.

[111] USDA ERS. (2011). 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

3. Results

3.1 Results overview

This section provides an overview of results followed by more detailed summaries for each socioeconomic indicator. Data for each indicator are presented in either a line graph or table format. Line graphs for Debt to Asset Ratio, Agriculture Contribution to National GDP, Non-Fatality Injury, Fatalities, and Labor Hours are presented with regression equations and R2 values. The line graphs provide additional resolution regarding changes over time and the conformity of those changes with average trend line for the full study period.

Results are also highlighted and discussed in text for each crop and indicator. It should be noted that in both the results and conclusions sections, we have purposefully avoided speculation regarding the practice, contexts and drivers that influence the outcomes estimated through this analysis. Field to Market recognizes that management decisions by U.S. agricultural producers are guided by many factors, including international price signals, Farm Bill policies and programs including 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 interpretation, including at the more geographically-specific scale needed to understand some trends, is beyond the scope of this report.

- **Debt to asset ratio** (1996-2010)
  - o The debt to asset ratio decreased (improved) (-37%) for general cash grain farms.
- **Returns over variable costs** (1980–2011)
  - o Returns over variable costs for corn, rice, soybeans and wheat decreased during the 1980s, increased in the early to mid-1990s with a slight decrease in the late 1990s and an increase beginning in approximately 2002, providing a w-shaped curve for the time period.
  - o Returns over variable costs for cotton decreased in the early 1980s, maintained flat growth with some variability from the late 1980s to approximately 1998, and then decreased again until the early 2000s when returns stabilized. There has been an increase in returns over variable costs for cotton since approximately 2009.
- **National and state gross domestic product** (GDP)(1997–2009)
  - o The national growth rate trend has increased (69%) for the agricultural sector contribution to the national GDP.
- **Non-fatality injury** (1995–2010)
  - o The number of work related injuries decreased (-55%) for all crop-producing farms with eleven or more employees.
  - o The number of lost work days (-76%) and the incidence of one or more work days lost (-49%) due to injury both decreased for crop farms (excluding fruit, vegetable, and other specialty crops).
- **Fatality** (1993–2010)
  - o Fatalities decreased (-32%) for crop farms (excluding fruit, vegetable, and horticulture farms).
- **Labor hours** (1990–2011)
  - o The implied time to produce corn (-59%, -75%), cotton (-69%, -75%), rice (-43%, -58%), and soybeans (-66%, -74%) decreased both per acre and per unit of production, respectively.
  - o The implied time to produce wheat decreased (-12%) per bushel but remained relatively flat (-1%) per planted acre.

In summary, the indicators for debt to asset ratio, fatalities, and non-fatality injury decreased (improved) over their respective time periods and farm classification. Returns over variable costs have been inconsistent over the indicator's respective time period, but have been increasing for all crops, excluding cotton, since approximately 2002, and for cotton since 2009. Labor hours have decreased for all crops per unit of production and, excluding wheat, per planted acre. Overall, the agricultural sector's contribution to national GDP has increased over the explored time period in absolute terms but decreased as a share of total.

Results for the individual indicators are detailed in the sections below. **Tables 2.2 and 2.3** summarize data for all socioeconomic indicators.

Table 2.2 Socioeconomic Summary of Results 1

Socioeconomics Summary of Results 1: United States Trends						
Indicator	Crop	Measurement	Time Period	Percent Change* 1980-2011		
				Trend Direction	Entire Period	Compound Annual
Debt/Asset Ratio	Cash Grain Farms	Percent	1996-2010	↓	(37)	(3.2)
Contribution to National GDP - Crops and Livestock	Total Crops and Livestock	Billions - Nominal	1997-2010	↑	69	4.1
		Share of Total	1997-2010	↓	(11)	(0.9)
Non Fatal Injury	U.S. Crop Farms excluding Fruit, Vegetables and Horticulture Farms	Non-fatal Injuries - Number	1994-2010	↓	(55)	(4.8)
		Workdays Lost	1995-2010	↓	(76)	(9.2)
		One or More Days Lost	1995-2010	↓	(49)	(4.3)
Fatalities		Number of Fatalities	1993-2010	↓	(32)	(2.2)
Labor Hours	Corn	Hours/Planted Acre	1990-2011	↓	(59)	(4.1)
		Hours/Bushel	1990-2011	↓	(75)	(6.3)
	Cotton	Hours/Planted Acre	1990-2011	↓	(69)	(5.5)
		Hours/lb Lint	1990-2011	↓	(75)	(6.5)
	Rice	Hours/Planted Acre	1990-2011	↓	(43)	(2.7)
		Hours/cwt	1990-2011	↓	(58)	(4.0)
	Soybeans	Hours/Planted Acre	1993-2011	↓	(66)	(5.8)
		Hours/Bushel	1993-2011	↓	(74)	(7.1)
	Wheat	Hours/Planted Acre	1993-2011	↓	(1)	(0.1)
		Hours/Bushel	1993-2011	↓	(12)	(0.7)

*Percent change results are based on a least squares trends analyses for the time period indicated.

Table 2.3 Socioeconomic Summary of Results 2

Socioeconomics Summary of Results 2:
United States Trends

Indicator	Crop	Measurement	Time Period	Real Dollar Value (1980 to 2010)			
				2010 Level	Mean	Min	Max
Net Returns Above Variable Costs (Real year 2000 dollars)	Corn	$/Acre	1980-2010	258.3	151.6	106.0	299.3
		$/Bushel	1980-2010	2.1	1.1	0.7	2.5
	Cotton	$/Acre	1980-2010	112.1	149.5	99.7	196.2
		$/lb Lint	1980-2010	0.2	0.2	0.1	0.4
	Rice	$/Acre	1980-2010	380.0	208.4	126.7	396.3
		$/cwt	1980-2010	5.5	3.5	2.3	6.7
	Soybeans	$/Acre	1980-2010	228.1	173.2	129.0	255.4
		$/Bushel	1980-2010	5.5	5.0	3.4	8.0
	Wheat	$/Acre	1980-2010	93.3	68.1	48.1	108.3
		$/Bushel	1980-2010	2.5	2.1	1.4	3.5

3.2 National Debt to Asset Ratio

Data from the USDA's Economic Research Service for the years 1996 through 2010 indicate continued strengthening of the financial position (measured by the debt-to-asset ratio) for U.S. farms that specialize in the production of cash grains (**Figure 2.2**). By 2010, the most current year that data are available, the ratio was at 11.4 compared with 16.6 in 1996. 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 have seen record income levels over the past several years that have caused land values to increase and producers to pay cash for purchases that might otherwise have been financed. In contrast, farms that specialize in pork, poultry, or dairy have tended to operate at debt to asset ratios nearly double of that of their cash grain counterparts. The recent decline in the financial position of livestock farms can be explained in part by the sustained increase in feed cost experienced in the past 5 years. The livestock sector cannot adjust to these factors quickly.

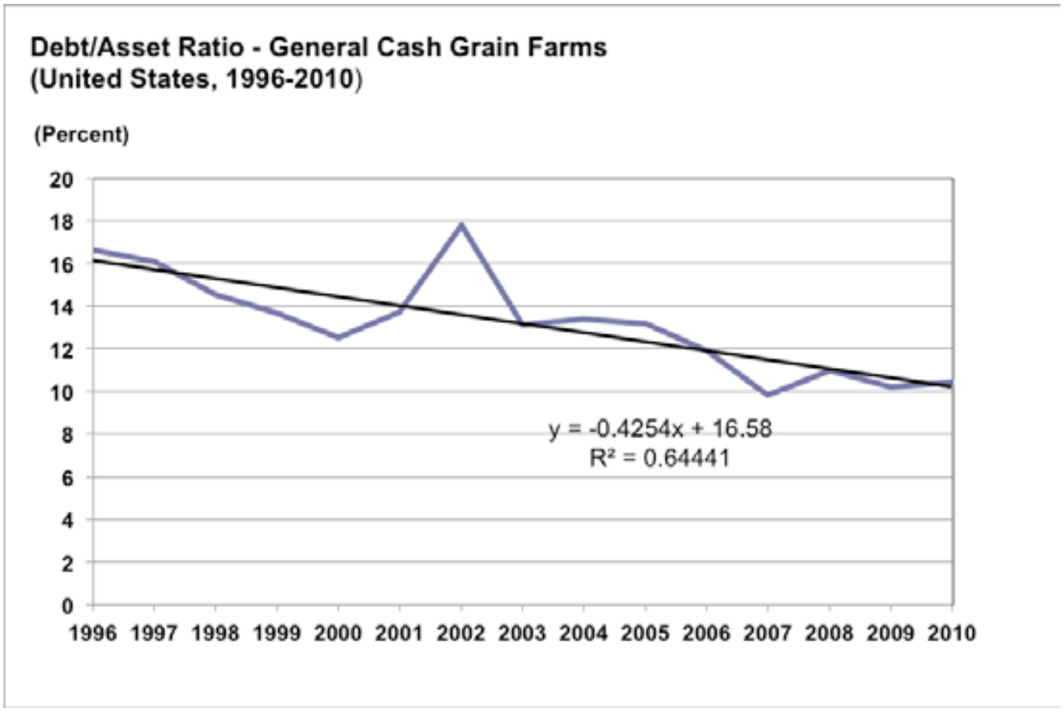


Figure 2.2 Debt/Asset Ratio, General Cash Grain Farms, United States 1996-2010

Please note, in the graph above, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient has the unit of percent. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

3.3 Real Returns Above Variable Costs

Several factors can impact the returns above variable costs for crop producers. Over a long period of time, sustained increases in the growth rate for purchased inputs can reduce the net margin if output prices do not move at the same rate. Also over the long run, increase 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 burnt to establish the crop and care for it. In the very short term, a given growing season, the most significant factor impacting net returns will be output price changes and yield variation due to weather. One contrast between the impacts of the two previously mentioned factors is that commodity prices from one region to another tend to move together, e.g., the corn price in the Midwest will not move dramatically in any direction without corn prices in other regions moving in the same direction. Variation caused by yield, usually to the downside, is typically isolated to a single geographic area and may or may not have a significant impact on output prices. The price received that is used in the calculation of crop revenue is based on a harvest period price including 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.

According to a recent USDA analysis of U.S. farm financial performance, total returns on farm business assets (from current income plus capital gains) are estimated at 8.6 percent in 2010 (with 2.1-percent growth in returns from current income and 6.5-percent growth in returns from capital gains). Given the continued strong farm income situation and growth in farmland values, the situation for 2011 appears to have continued to strengthen.[105]

The following figures by crop are all national data based on 5 year moving averages and include both the income and expense from crop insurance as well as the income from government programs for which payment is dependent on producing the crop, for example loan deficiency payments. While loan deficiency payments have decreased significantly in the past few years due to stronger market prices, they are a legacy factor in USDA Return above Variable Costs calculations.

Corn

Measured in year 2000 currency, real net returns from corn production averaged $167 per acre (not including land costs) over the period 1980 to 2011, sank to a low of $60 in 1986, and rose to a peak of $382 in 2010. On a per bushel basis, corn net returns above variable costs (not including land costs) averaged $1.20 and experienced a low in 1986 of $0.33 and a high of $3.44 per bushel in 2011. During the period 1980 to 2011, corn returns have seen sustained periods of strength during the early years (through the middle 1980s) and more recently since 2006 to present. The largest determinant in the years of strong commodity prices was high corn prices. Charted averages are 5 year moving averages (**Figure 2.3**).

[105] USDA ERS. 2011).Agricultural Income and Finance Outlook. Washington, D.C.: United States Department of Agriculture Economic Research Service. http://usda01.library.cornell.edu/usda/current/AIS/AIS-12-14-2011.pdf

Cotton Lint

Cotton yields have experienced relatively consistent growth over time with a long-run trend of about 1% annually over the past 30 years. Yield on a planted acre basis reached a record high driven by very favorable weather across most regions, particularly Texas. These strong yields and, more recently, a near doubling in the season average price have caused real net returns above variable cost to begin to increase or at least stabilize (**Figure 2.4**). The farm level cotton price has increased from $0.42 per pound in 2004 and is anticipated to increase to approximately $0.92 per pound in 2011/2012 marketing year. The run up in cotton prices was a few years behind that which occurred in most grain and oilseed crops and consequently caused a significant drop in area devoted to cotton production. Cotton has seen considerable increases in its cost over time as have many crops. Crop insurance is a widely used program and production challenges in recent years have caused crop insurance payouts to be considerable.

Rice

Similar to other grain crops, rice in the early 1980s experienced high prices on an inflation adjusted basis and 5 year average net returns reached a high $303 per acre and $6.66 per cwt. in 1984 (Figure 2.5). 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 cwt. High crop output prices in recent years and strong yields have allowed per acre net returns to rise above the past highs and reached nearly $400 in real dollars (year 2000). Rice returns per cwt continued to rise in recent years, reaching $5.71 in 2011. Rice production in the United States is fully irrigated, thus reducing yield variation due to weather; this likely explains why the year-to-year variation in returns is less than for other crops, however a full analysis of drivers that is beyond the scope of this report would be necessary to confirm this.

Soybeans

Over the period 1980 through 2011 soybeans real net returns above variable costs averaged $5.31 per bushel with a high of $11.06 in 1980 and a low of $3.06 in 2006. Returns in 2011 are projected to have been approximately $7.00 per bushel. On a real year 2000 basis, the low for per acre net returns was $126 in 1999 and the high is projected for 2011 at $286. The average for the period is $183, year 2000 dollars, per planted acre. Charted averages are 5 year moving averages (**Figure 2.6**).

Wheat

Wheat returns adjusted for inflation (real 2000 dollars) peaked in the early 1980s due to high real crop prices and generally favorable yields in the United States. In 1984 the 5-year average per acre real returns hit $108 and fell to a low $48 in 2005. The sustained rise in grain price over the last several years has pushed real returns back up to $106 in 2011. The average for the period was $68 per acre. On a per bushel basis, high and low wheat returns coincided with the same years as the per acre measure. The 5 year average per bushel returns for the period 1989 through 2011 were $2.07 with a low of $1.42 in 2005 and $3.46 in 1984 (**Figure 2.7**).

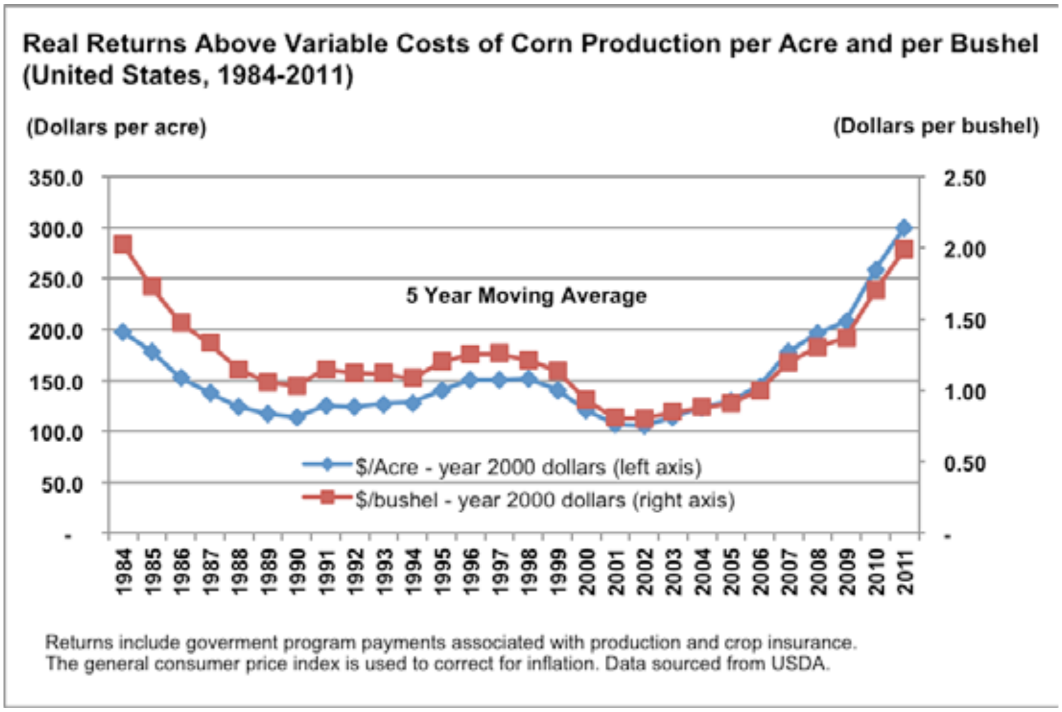


Figure 2.3 Real Returns Above Variable Costs of Corn Production per Acre and per Bushel, United States 1984-2011

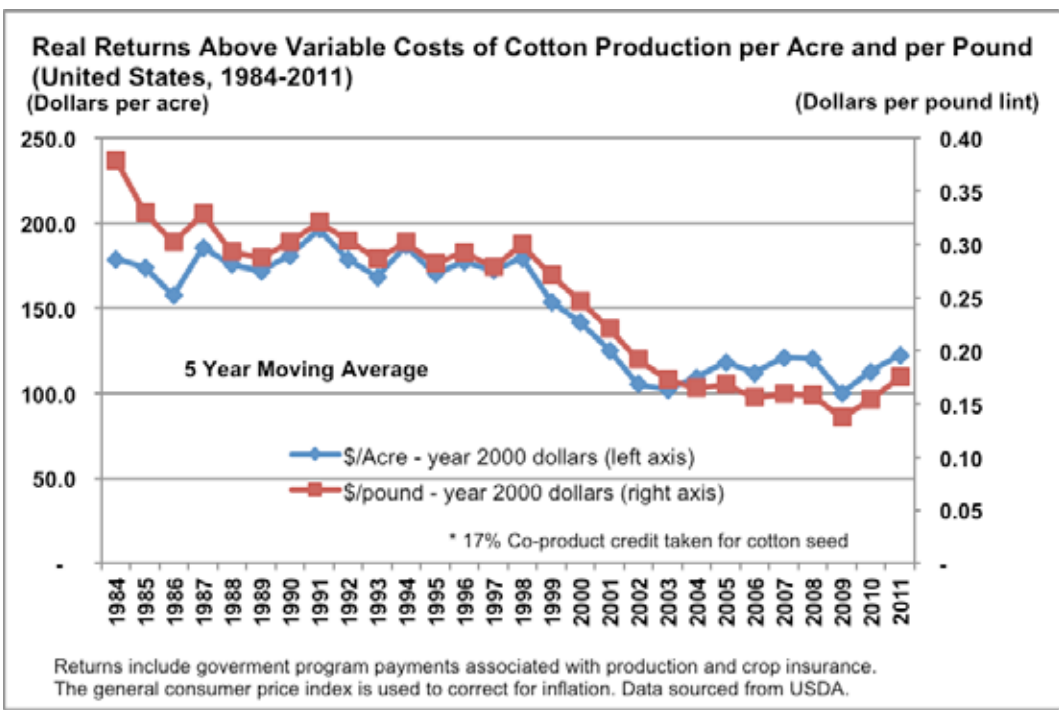


Figure 2.4 Real Returns Above Variable Costs of Cotton Production per Acre and per Pound, United States 1984-2011

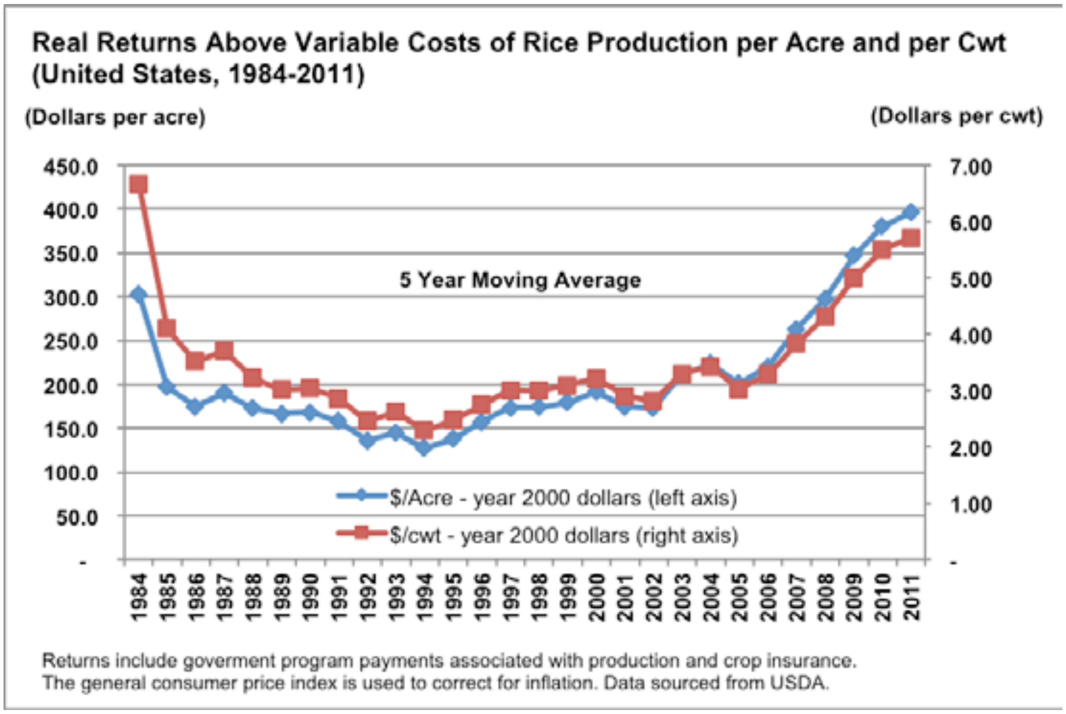


Figure 2.5 Real Returns Above Variable Costs of Rice Production per Acre and per Cwt, United States 1984-2011

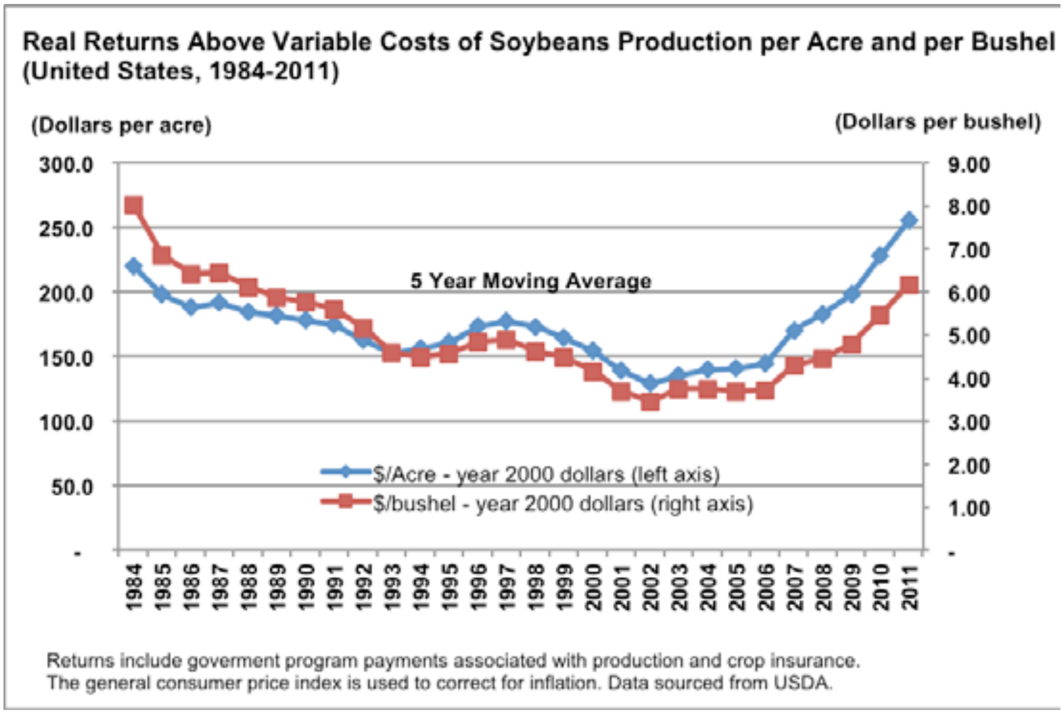


Figure 2.6 Real Returns Above Variable Costs of Soybeans Production per Acre and per Bushel, United States 1984-2011

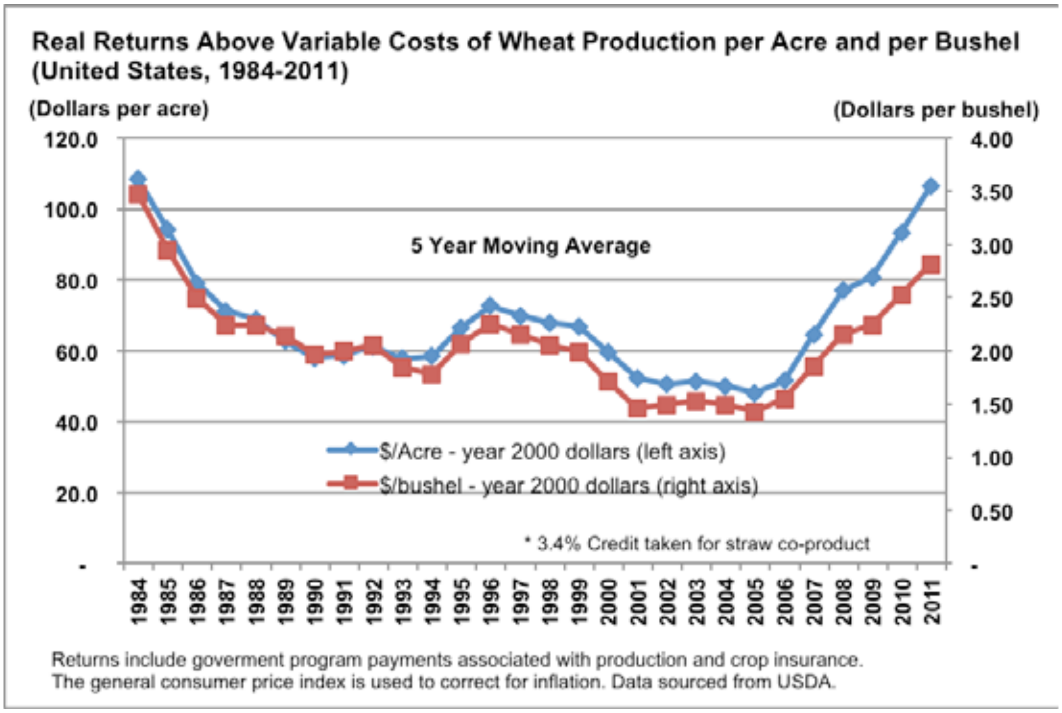


Figure 2.7 Real Returns Above Variable Costs of Wheat Production per Acre and per Bushel, United States 1984-2011

Regional Real Returns Over Variable Costs

Corn

Regional data for corn net returns are presented for the years 1996 through 2010. While the regional returns have a pattern of better profits in the early years as well as the most recent years some regional dispersion does occur during the period. In 1998 the Southern Seaboard region saw a dramatic dip in corn yields in 1998 to 64 bushels per planted acre while many other regions saw favorable growing conditions. During 2008 and 2009 the Southern seaboard and the Northern Crescent saw relatively poor productivity levels while other regions saw favorable levels causing these regions to significantly underperform the other regions.

See **Figures 2.8, 2.9 and 2.18** for more detail regarding corn regional real returns over variables costs results.

Cotton Lint

Real net returns for cotton lint by region are considerably variable over time with those for the Prairie Gateway (largely Texas) being the most variable and averaging the lowest over the period of 7 cents per pound over the 1997 to 2010 time period. With respect to the Prairie gateway region most all crops experience considerable production variation due to moisture stress and yield variability. Please note that for cotton lint production, the Heartland region includes Missouri only.

See **Figures 2.10, 2.11 and 2.19** for more detail regarding cotton lint regional real returns over variables costs results.

Rice

The Mid-South and Gulf Coast rice-growing regions primarily produce long-grain rice, while California produces primarily medium and short-grain rice. Long-grain rice has a significantly different price and market situation, with recently lower prices, on average, than medium and short-grain rice prices. Part of this is due to the uses of the different types of rice, and because some of the export-market demand for U.S. medium-grain rice is the result of previously-negotiated trade agreements that require certain levels of U.S.-rice imports.

See **Figures 2.12, 2.13 and 2.20** for more detail regarding rice regional real returns over variables costs results.

Soybeans

Regional soybeans cost and returns data for the period 1997 through 2010 are available from USDA. Over that period the Eastern Upland and Southern Seaboard regions saw significant declines in real returns in 1999 due to low yields. In 1999 per acre net returns in the Eastern Uplands dropped to $15 dollars per acre due to a significant yield decline to only 22 bushels per acre.

See **Figures 2.14, 2.15 and 2.21** for more detail regarding soybeans regional real returns over variables costs results.

Wheat

On a regional basis the dominant wheat growing areas (Northern Great Plains and the Prairie Gateway) experience the greatest range of net returns while less significant growing areas (many of which are East of the Mississippi) experience much less variation in returns. For both Prairie Gateway and Northern Great Plains, annual rainfall is relatively low, wheat is not irrigated and wheat is grown on a very large acreage. All of these factors could contribute to variability in returns (as well as abandonment of land). While the dominate wheat growing areas see the greatest variation in net returns from one year to the next they tend to be the regions that have seen the highest peaks in net returns. The Southern Seaboard was near zero (0) for returns, while returns were positive for other regions.

See **Figures 2.16, 2.17 and 2.22** for more detail regarding wheat regional real returns over variables costs results.

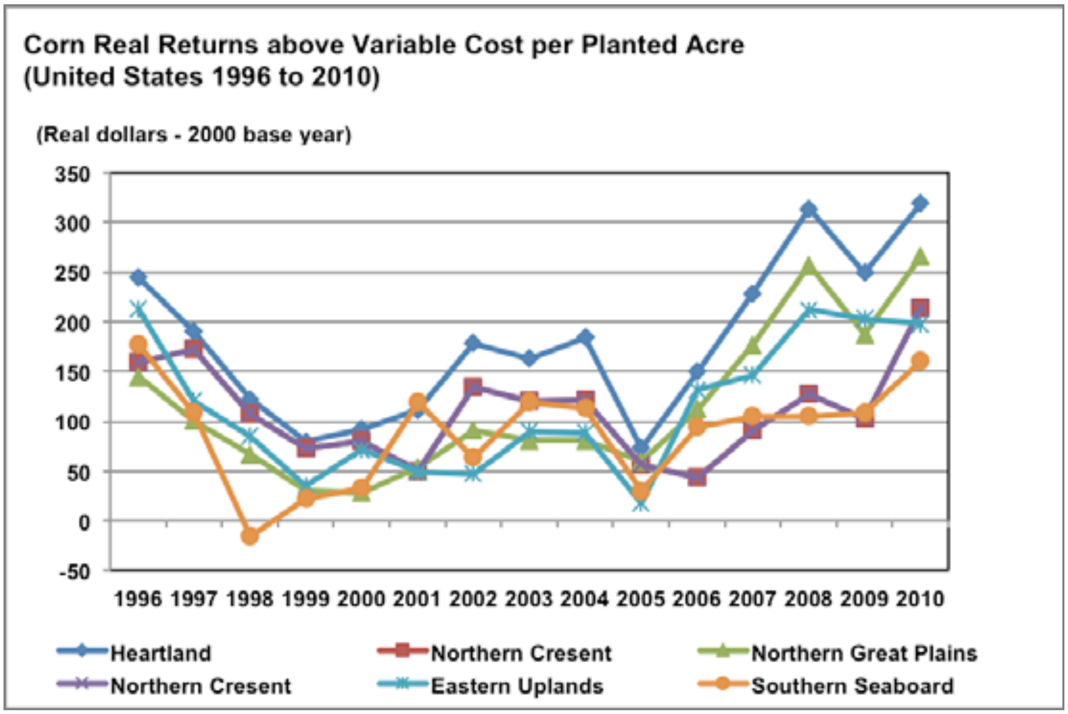


Figure 2.8 Corn Real Returns above Variable Costs per Planted Acre, United States 1996-2010

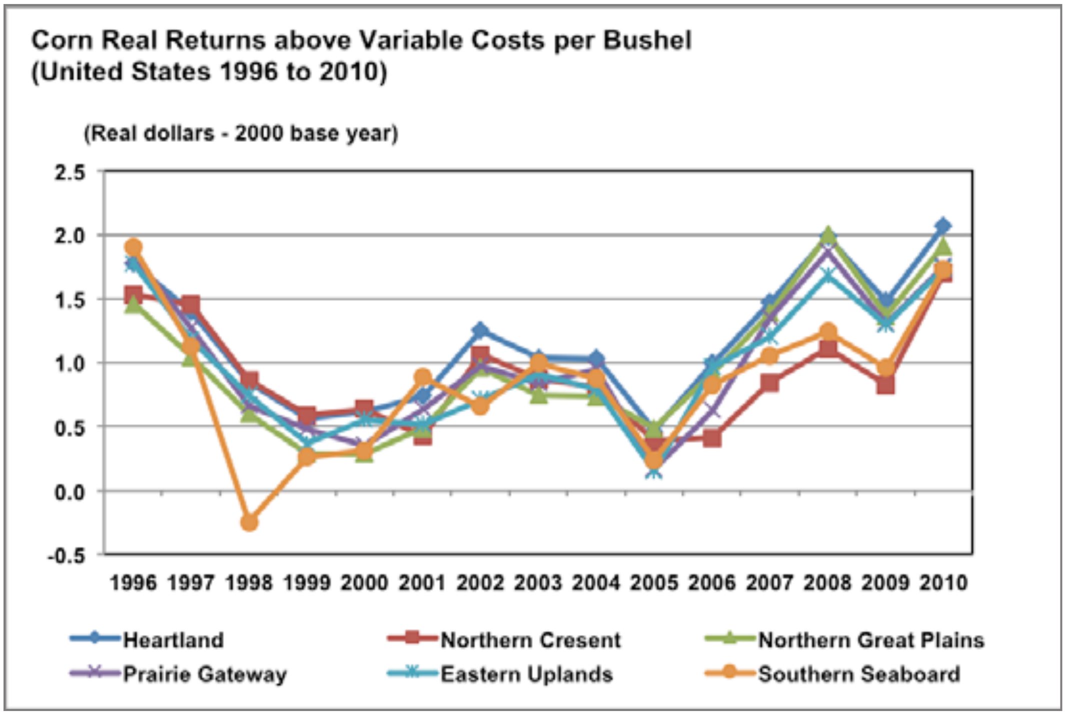


Figure 2.9 Corn Real Returns above Variable Costs per Bushel, United States 1996-2010

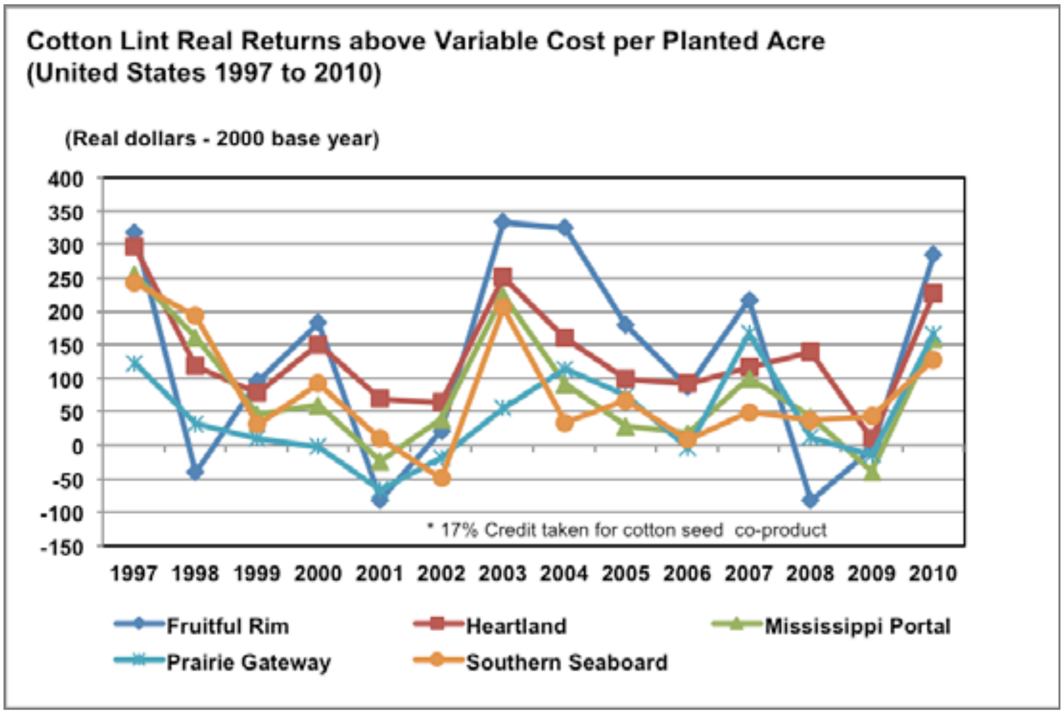


Figure 2.10 Cotton Lint Real Returns above Variable Costs per Planted Acre, United States 1997-2010

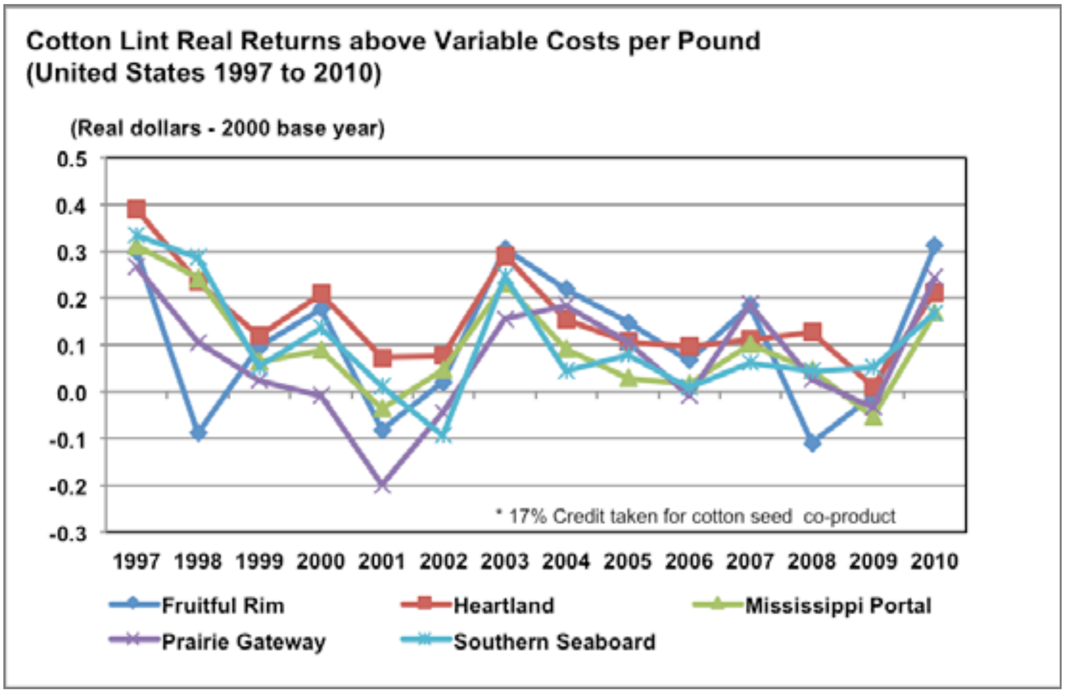


Figure 2.11 Cotton Lint Real Returns above Variable Costs per Pound, United States 1997-2010

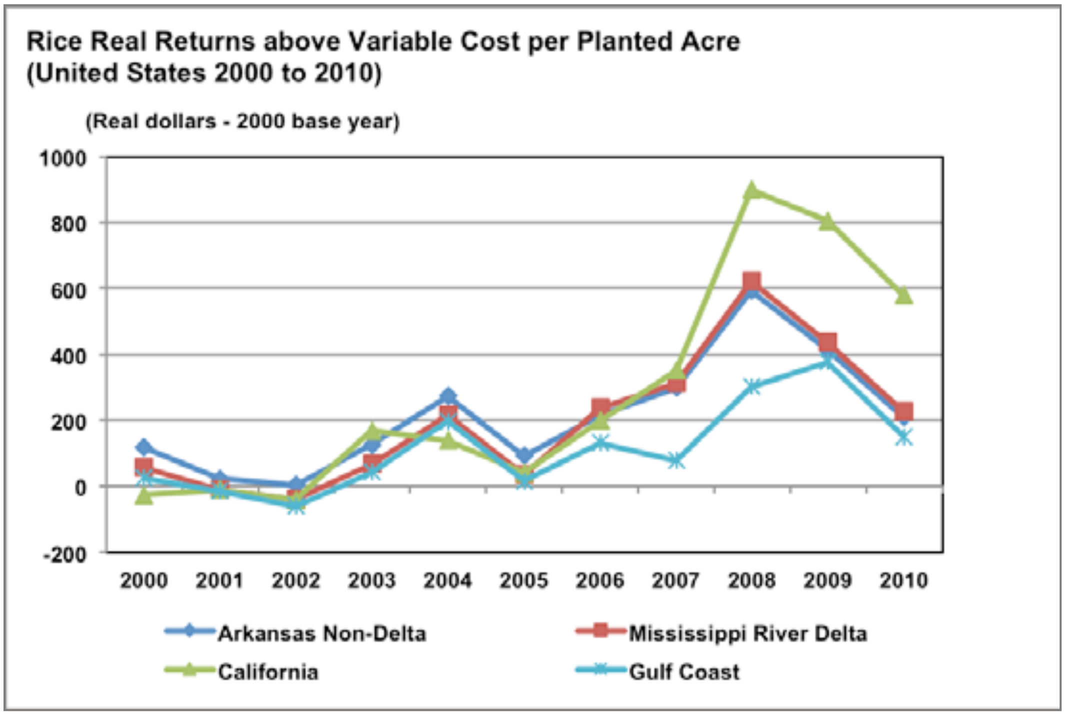


Figure 2.12 Rice Real Returns above Variable Costs per Planted Acre, United States 2000-2010

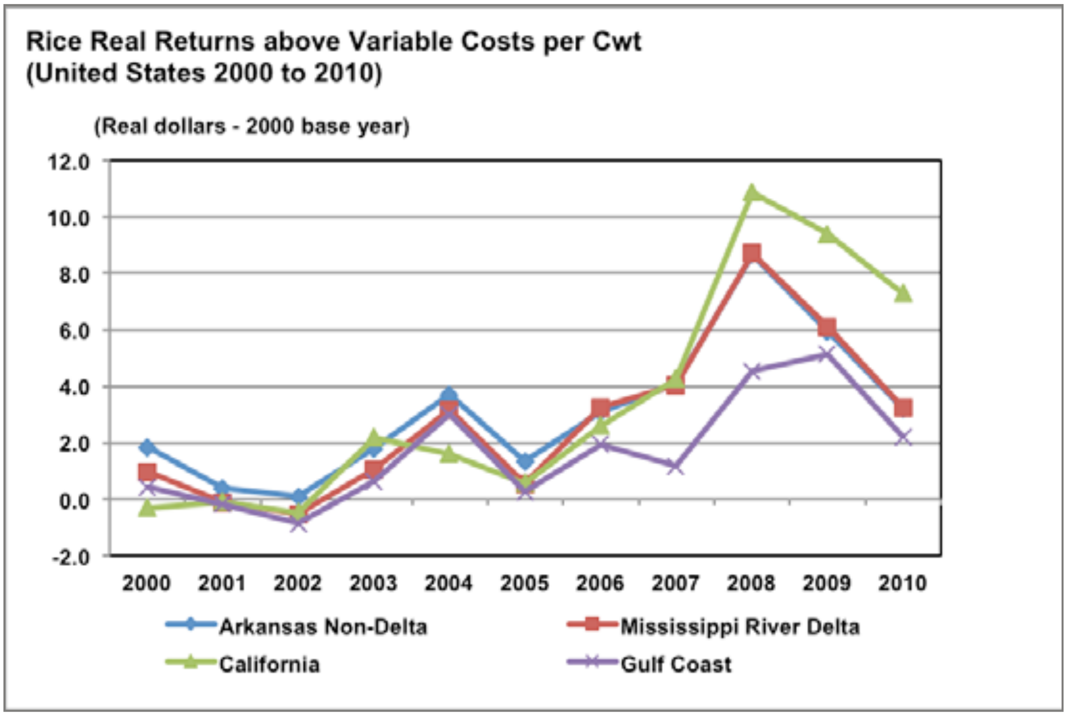


Figure 2.13 Rice Real Returns above Variable Costs per Cwt, United States 2000-2010

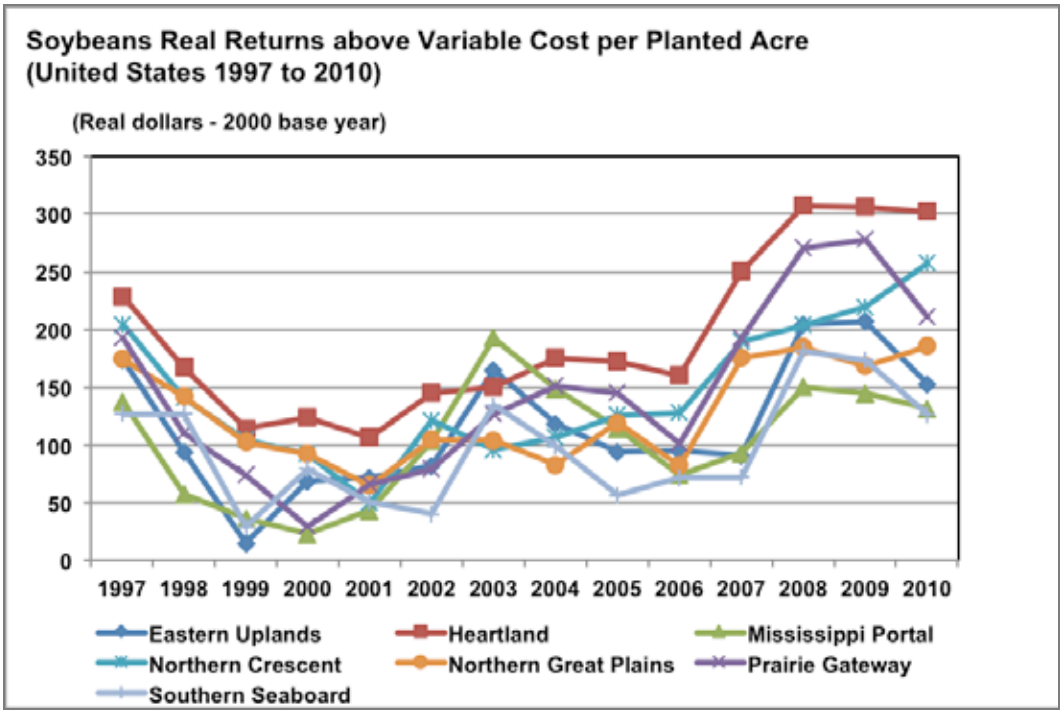


Figure 2.14 Soybeans Real Returns above Variable Costs per Planted Acre, United States 1997-2010

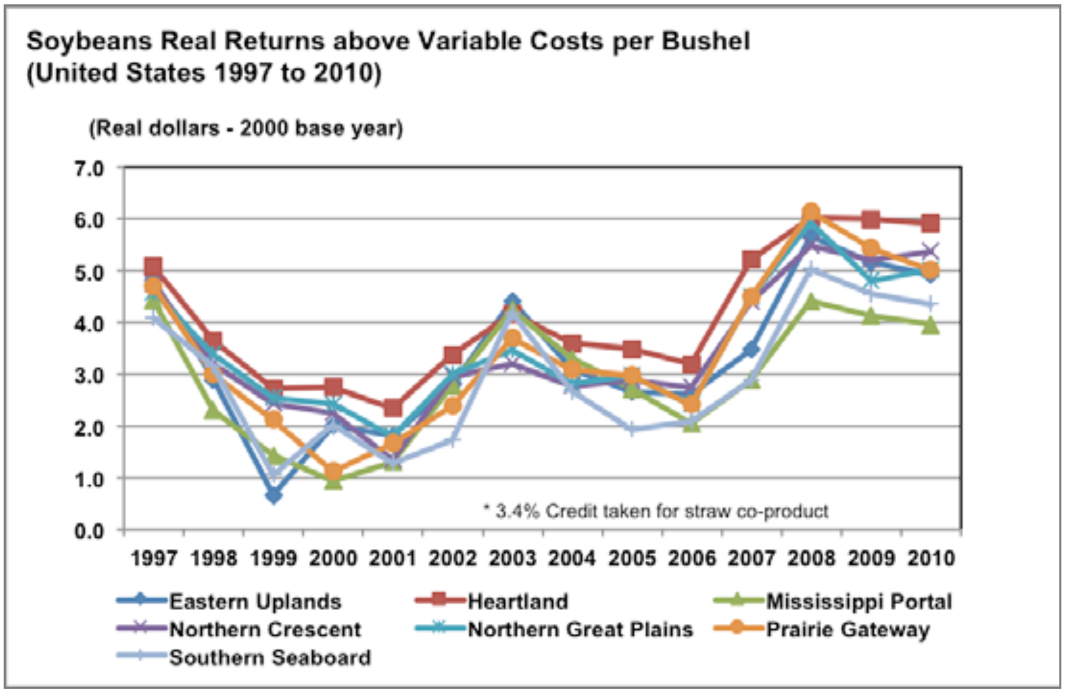


Figure 2.15 Soybeans Real Returns above Variable Costs per Bushel, United States 1997-2010

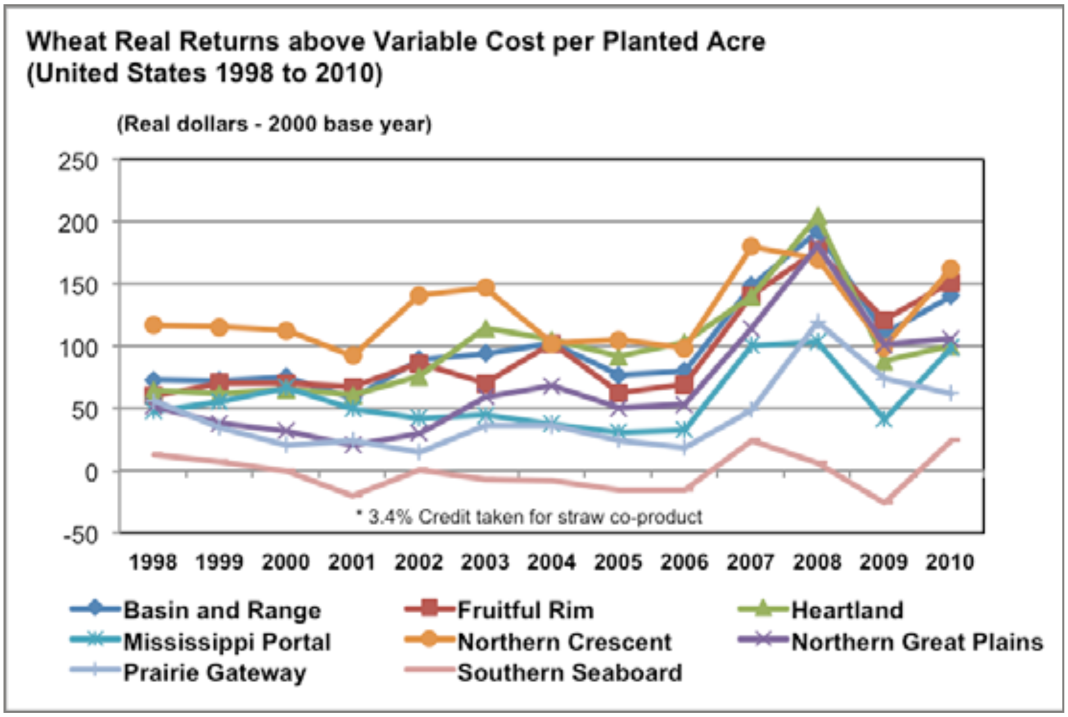


Figure 2.16 Wheat Real Returns above Variable Costs per Planted Acre, United States 1998-2010

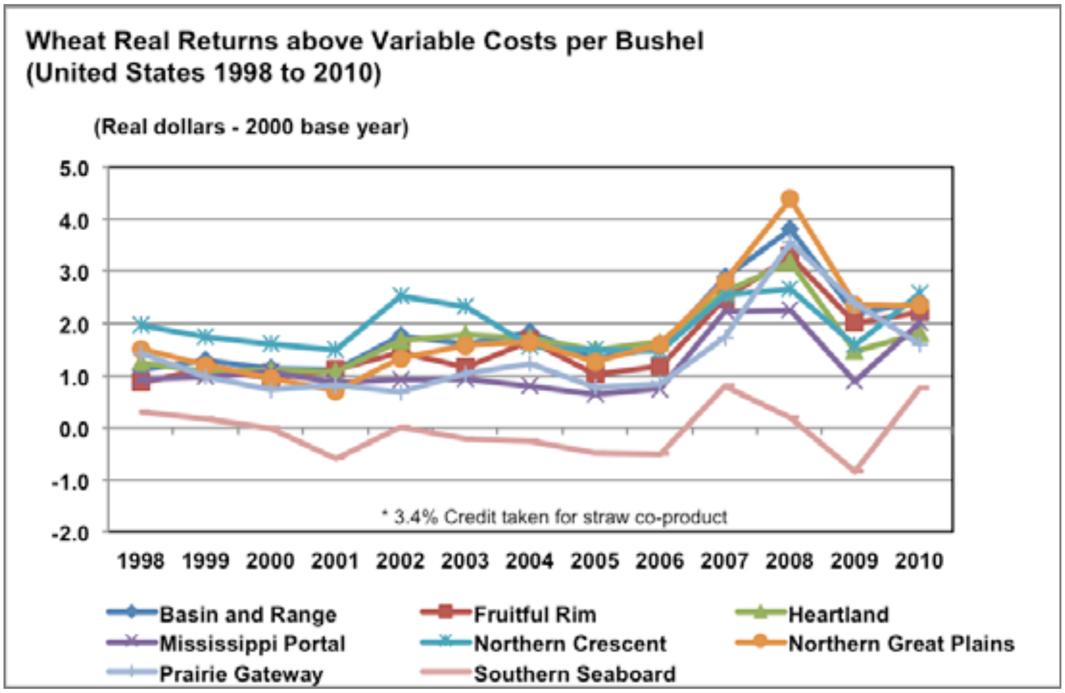


Figure 2.17 Wheat Real Returns above Variable Costs per Bushel, United States 1998-2010

Regional Real Returns above Variable Costs: Mean, Minimum, Maximum

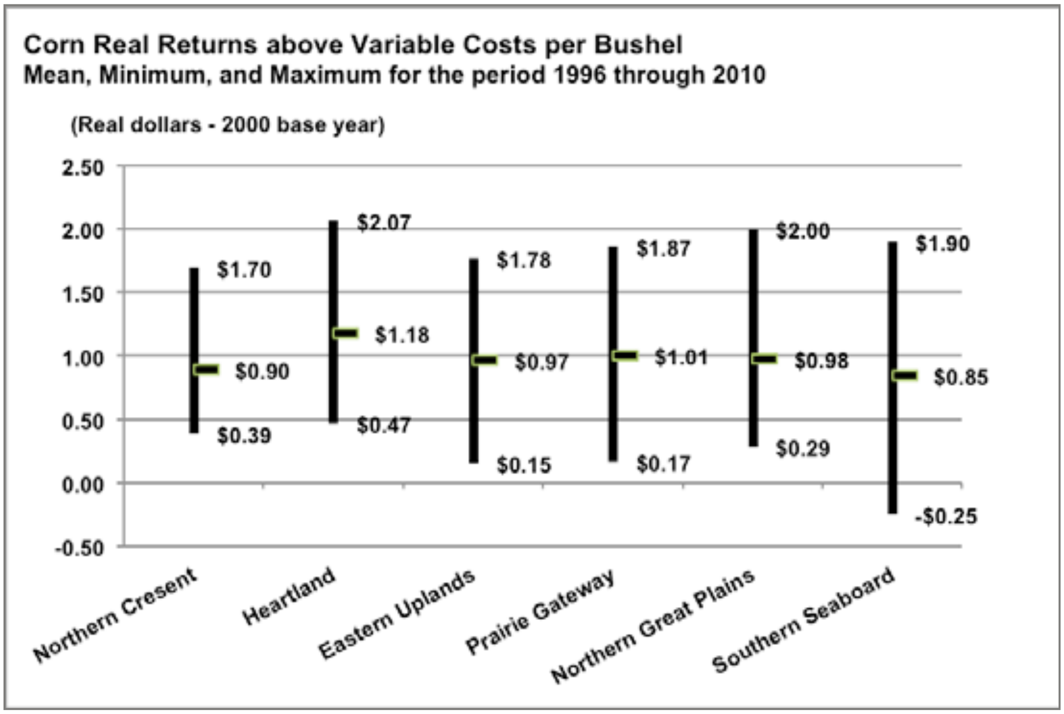


Figure 2.18 Corn Real Returns above Variable Costs per Bushel: Mean, Minimum, Maximum, United States 1996-2010

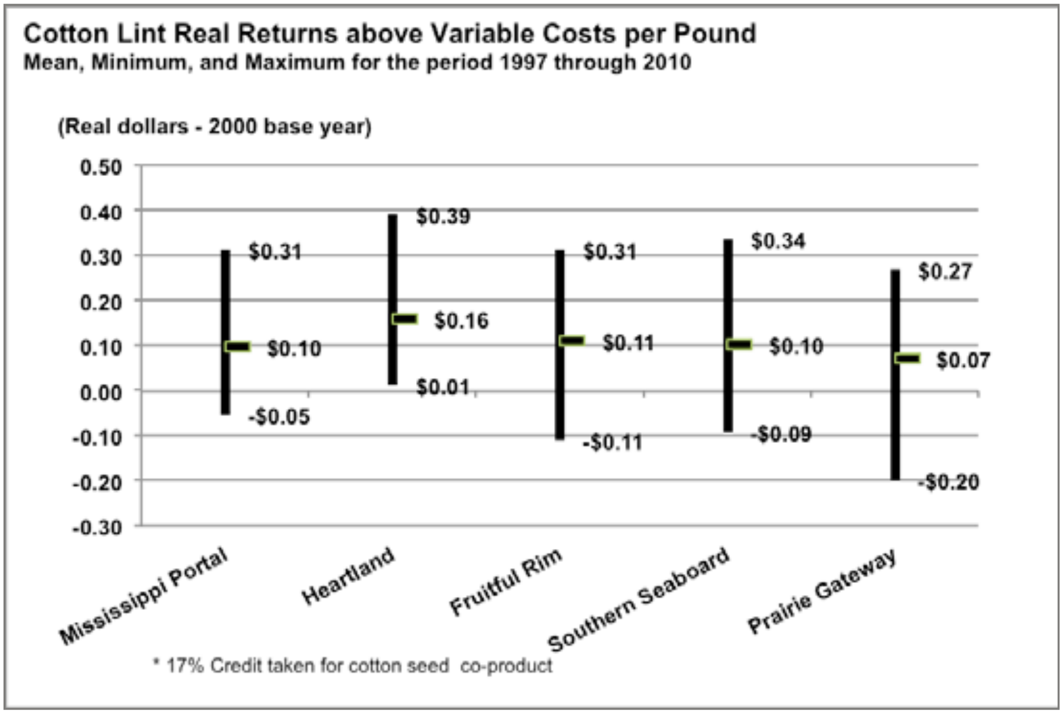


Figure 2.19 Cotton Lint Real Returns above Variable Costs per Pound: Mean, Minimum, Maximum, United States 1997-2010

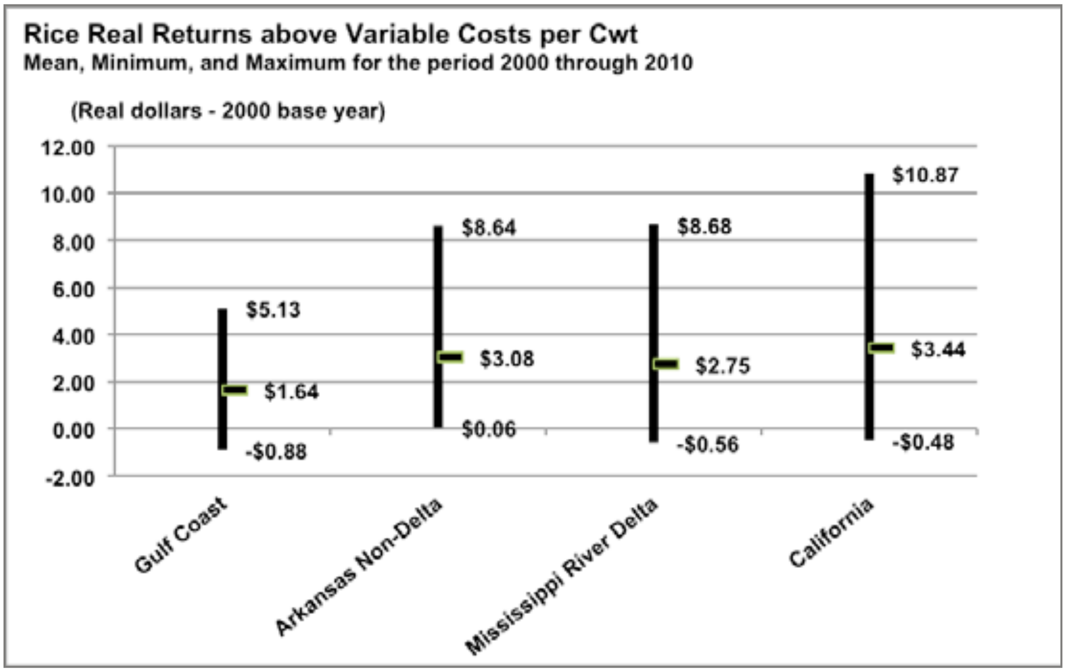


Figure 2.20 Rice Real Returns above Variable Costs per Cwt: Mean, Minimum, Maximum, United States 2000-2010

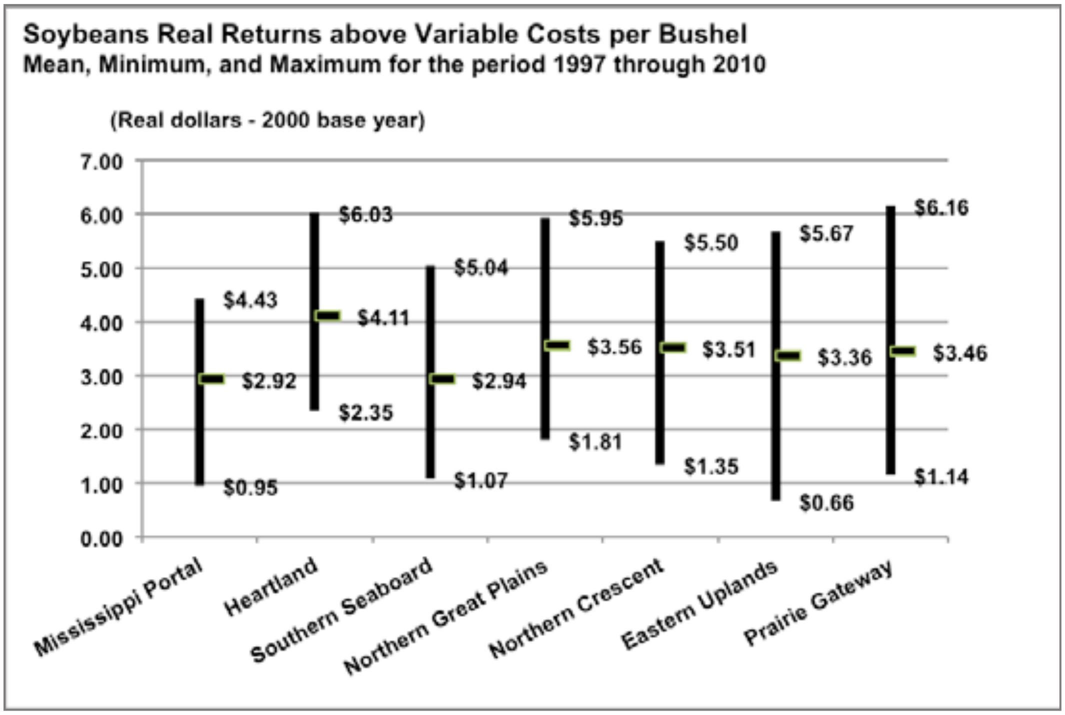


Figure 2.21 Soybeans Real Returns above Variable Costs per Bushel: Mean, Minimum, Maximum, United States 1997-2010

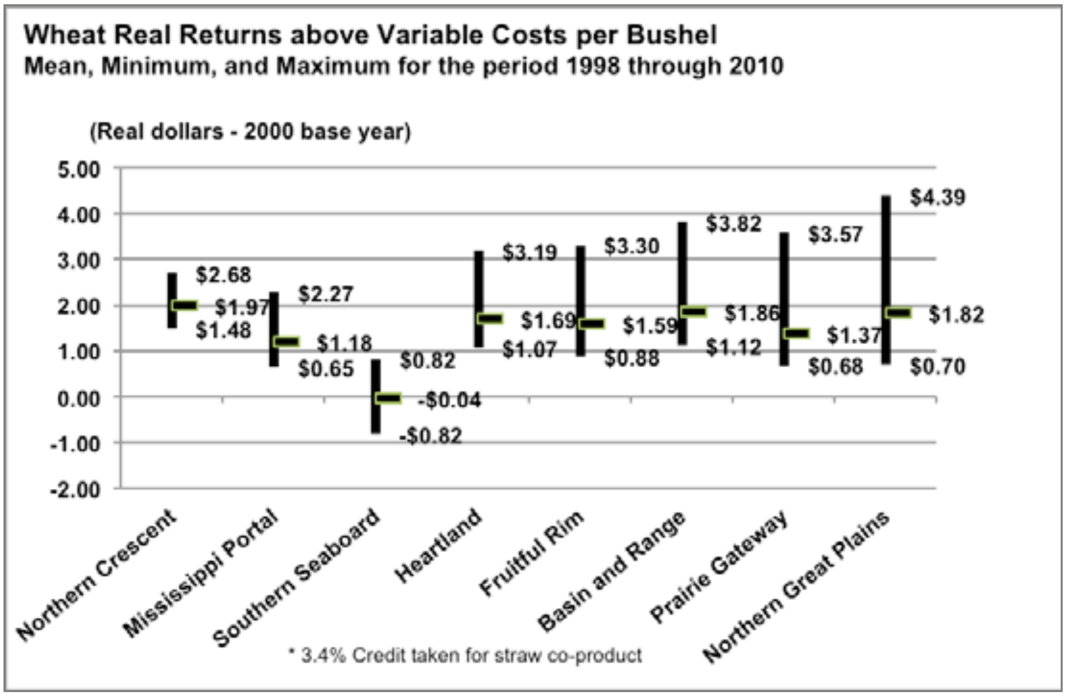


Figure 2.22 Wheat Real Returns above Variable Costs per Bushel: Mean, Minimum, Maximum, United States 1998-2010

3.4 Agricultural Contribution to National and State GDP

The value of production from the crop and livestock sectors of U.S. agriculture has increased roughly $3.8 billion per year over the period 1997 through 2009. While its absolute level has been rising, as a share of the national economy the crop and livestock sectors have been basically flat (**Figure 2.23**).

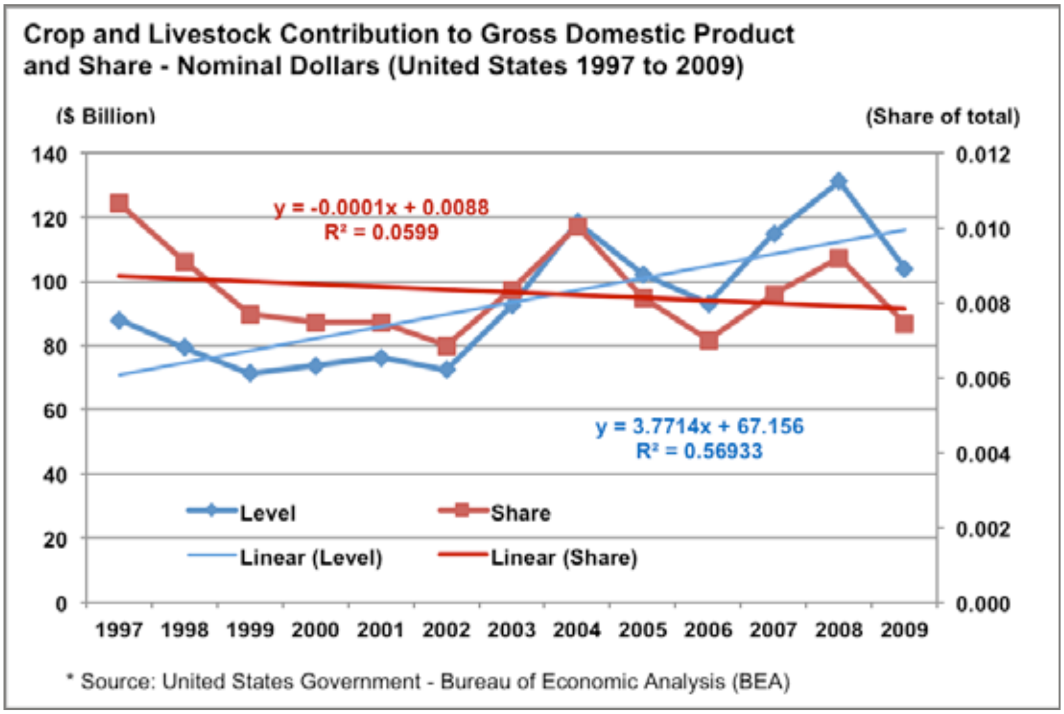


Figure 2.23 Crop and Livestock Contribution to Gross Domestic Product and Share – Nominal Dollars, United States 1997-2009

Please note, in the graph above, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient has the unit of the appropriate Y axis. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

The top 30 state agricultural contributions to National Gross Domestic Product (GDP) and their respective contribution to their State GDP are shown in **Table 2.4.** Agricultural contribution as defined by the USDA for available data includes all crops and livestock. In addition the table shows growth rate trends (1997-2009) and impact of agriculture on the state economy.

The top five states with the largest growth in agricultural contribution (crop and livestock) to state GDP are North Dakota, Nebraska, Iowa, Minnesota, and Missouri. North Dakota's agricultural contribution (crop and livestock) to state GDP is growing at a rate of 9.8 percent.

The top five states that contributed the largest agricultural (crop and livestock) share to their respective state GDP are North Dakota, South Dakota, Nebraska, Iowa, and Idaho.

Table 2.4 State Agricultural Contribution to National and Local GDP

	2005 to 2009 Average (Billion dollars)	Rank	Share of Nation	Cummulative Share	2005 - 2009 Trend Growth Rate	Share of the local economy
United States	109.01	1	100.0%		4.0%	0.8%
California	17.91	2	16.4%	16.4%	3.7%	1.0%
Texas	6.13	3	5.6%	22.1%	1.4%	0.6%
Iowa	5.93	4	5.4%	27.5%	7.3%	4.6%
Minnesota	4.62	5	4.2%	31.7%	8.3%	1.8%
Nebraska	4.34	6	4.0%	35.7%	6.9%	5.4%
Illinois	4.30	7	3.9%	39.7%	8.1%	0.7%
Florida	4.01	8	3.7%	43.3%	-0.2%	0.5%
Washington	3.62	9	3.3%	46.7%	4.8%	1.2%
North Carolina	3.26	10	3.0%	49.7%	0.6%	0.8%
Wisconsin	3.22	11	3.0%	52.6%	3.6%	1.4%
Kansas	3.17	12	2.9%	55.5%	5.5%	2.7%
Indiana	2.73	13	2.5%	58.0%	7.9%	1.1%
Missouri	2.72	14	2.5%	60.5%	7.5%	1.2%
Georgia	2.70	15	2.5%	63.0%	1.5%	0.7%
Ohio	2.52	16	2.3%	65.3%	3.8%	0.5%
South Dakota	2.46	17	2.3%	67.6%	6.8%	7.0%
Arkansas	2.40	18	2.2%	69.8%	2.5%	2.5%
Pennsylvania	2.35	19	2.2%	71.9%	3.1%	0.5%
Michigan	2.29	20	2.1%	74.0%	6.1%	0.6%
North Dakota	2.19	21	2.0%	76.0%	9.8%	7.7%
Idaho	2.13	22	2.0%	78.0%	5.2%	4.1%
Oregon	2.12	23	1.9%	79.9%	3.5%	1.3%
Colorado	1.96	24	1.8%	81.7%	4.0%	0.8%
Kentucky	1.86	25	1.7%	83.4%	1.5%	1.2%
New York	1.85	26	1.7%	85.1%	4.2%	0.2%
Oklahoma	1.69	27	1.5%	86.7%	2.0%	1.2%
Alabama	1.67	28	1.5%	88.2%	1.6%	1.0%
Mississippi	1.43	29	1.3%	89.5%	2.1%	1.6%
Arizona	1.31	30	1.2%	90.7%	1.0%	0.5%

3.5 Non-Fatality Injury

The US Bureau of Labor Statistics (BLS) reports detailed data on workplace injuries and fatalities by employment type as well as by the cause of the injury or death. The data have limitations given the reporting criteria for injuries are for firms with 10 or 11 or more employees. Given the reporting criteria, these data should be looked at more as an indication of trend and direction and not a measure of absolute magnitude. To put this reporting criterion in perspective, only 9 percent of all US farms in 2007 had eleven or more workers but farms with eleven or more workers represented about 57 percent of all farm labor. This indicator has significant regional variation with many more farms in California and Florida likely to meet the reporting criteria than farms in the Midwest.

Both crop farms and all of private industry have seen a considerable reduction in the incidence of injuries declining more than 50% since 1994. Labor employed in crop production experience an injury incidence of 4.4% compared with an overall industry level of 3.4%.

While recognizing the data limitations, crop-producing farms (excluding those producing fruits, vegetables, and other horticultural specialty crops) experienced considerable reductions from 1994 to 2010 in the number of reported injuries and the incidence of injury. The number of injuries declined from 31,000 to 16,000 cases and the incidence declined from nearly 9 percent to 4.4 percent (**Figure 2.24**). Data for the number of days lost per incidence implies that lost work days has decreased from roughly 32,000 workdays to about 11,000 days (**Figure 2.25**).

Please note, in the graphs below, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient has the unit of the appropriate Y axis. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

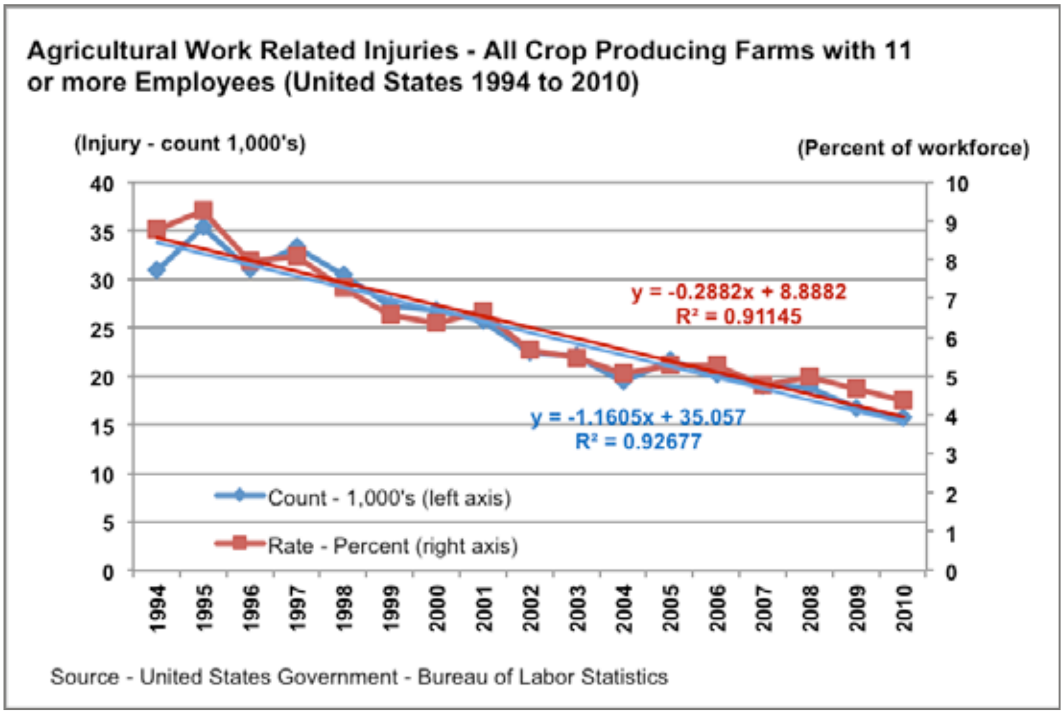


Figure 2.24 Agricultural Work Related Injuries – All Crops Producing Farms with 11 or more Employees, United States 1994-2010

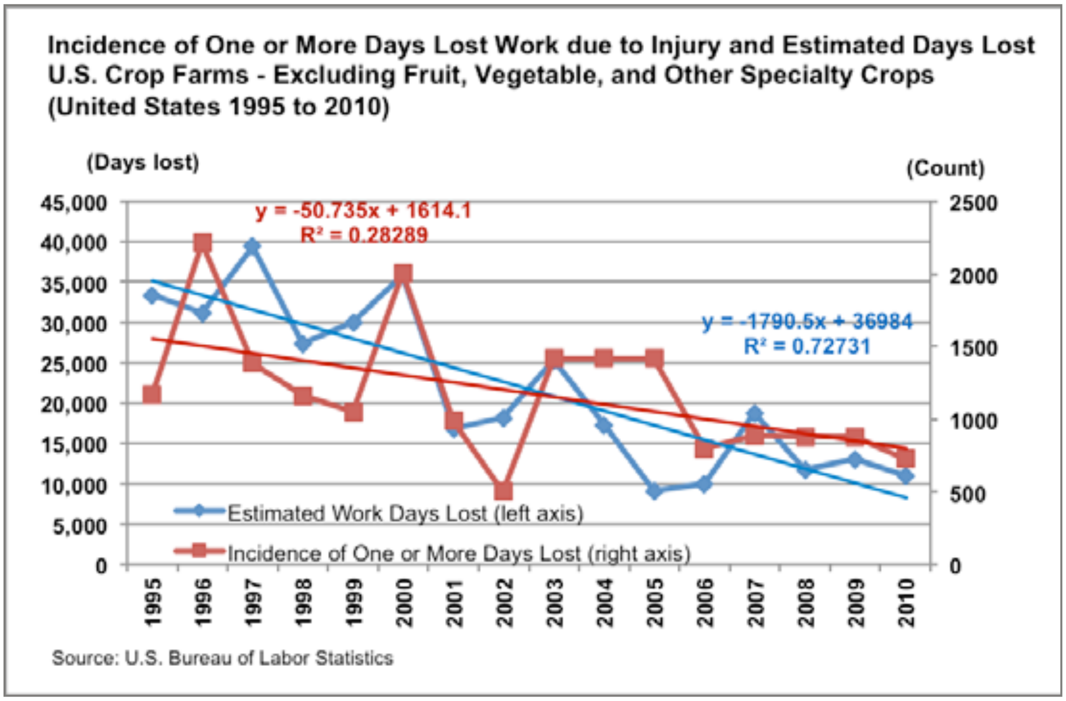


Figure 2.25 Incidence of One or More Days Lost Work due to Injury and Estimated Days Lost, U.S. Crop Farms – Excluding Fruit, Vegetable, and Other Specialty Crops, United States 1995-2010

3.6 National Fatalities

The US Bureau of Labor Statistics (BLS) reports detailed data on workplace injuries and fatalities by employment type as well as by the cause of the injury or death. Unlike injury data, in the case of fatality data there is no size threshold so all data are reported and categorized irrespective of number of employees.

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 2010 indicates an average fatality incidence of 28.7 occurrences per 100,000 employees while the private sector industry average is roughly 4 for the same period.

Agricultural employees suffer from a fatal injury incidence of roughly 7 times the industry average, The fatality incidence for the construction sector is nearly double the industry average but still one-third that of agriculture. While agriculture's fatality incidence level remains very high it needs to be noted that the trend is downward.

The number of fatal injuries on crop-producing farms (exclude those that specialize in vegetable, fruit, or other horticultural specialty crops such as tree-nuts) declined from 350 in 1994 to 264 in 2010 (Figure 2.26). The largest portion of fatal farm accidents occur in two areas: vehicle-related and contact with equipment or objects.

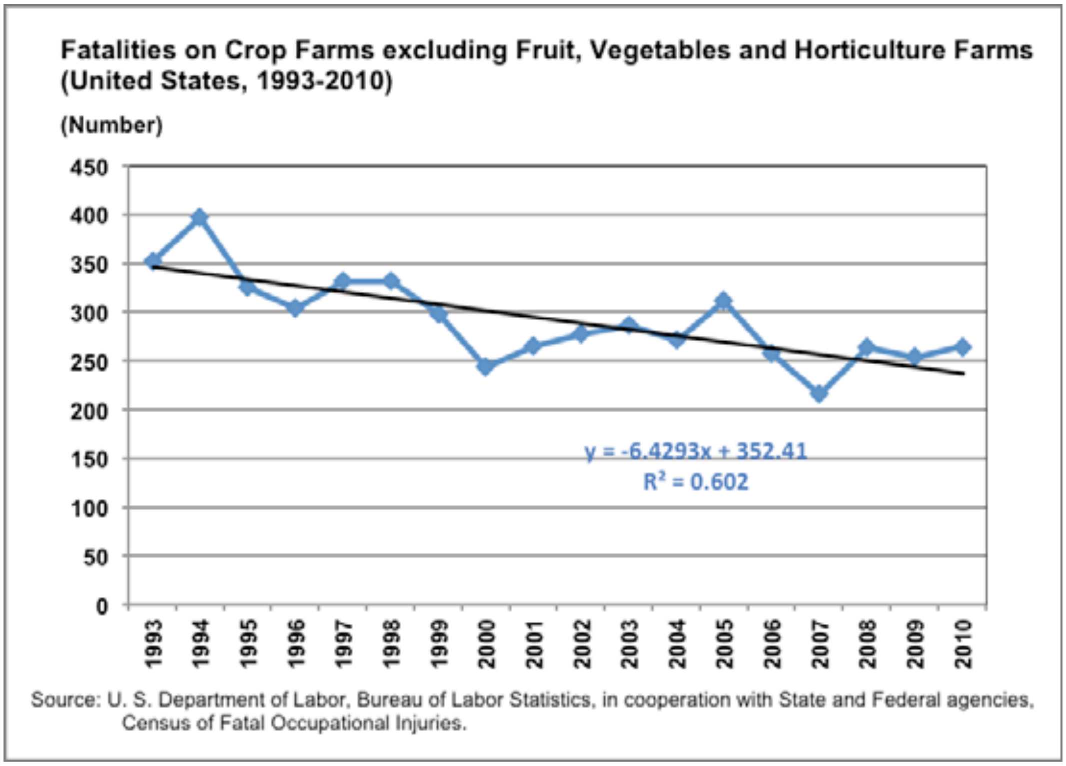


Figure 2.26 Fatalities on Crop Farms excluding Fruit, Vegetables and Horticulture Farms, United States 1993-2010

3.7 Implied Labor Hours

USDA data for the period 1990 through 2011 is presented to describe the implied amount of labor that is used to produce an acre and unit of output (e.g., labor hours per bushel of soybeans). A five-year moving average of the data is used to reduce the impact of year-to-year yield volatility, thus reducing the time period for the data to 1993 through 2011. The time period was selected because it appears data during this period is reported in a consistent format. The data used to assess the labor involved in crop production are the paid labor and value of unpaid labor divided by the labor rate for agricultural labor for crop production.

Agriculture has a strong trend toward increased efficiency in its use of both product inputs such as fuel and fertilizer as well as labor which can be from both paid and unpaid sources. When you measure the number of hours invested to produce an acre of a crop there are several technologies that have come to bear to make agriculture more productive over time. When measured in terms of hours per unit of production, positive trends in crop productivity make the efficiency gains even more pronounced. Among the technologies that agriculture is adopting that add to productivity are GPS navigation, auto-controlled equipment operation, and generally larger equipment overall. Most of these technologies have a compounding impact on efficiency change over time. There is good reason to believe that these trends will continue for quite some time given that their costs continue to decline allowing farmers of smaller scale to employee them.

Corn

The imputed hours to produce an acre and a bushel of corn have decreased considerably over the past 2 decades. Labor has been reduced from 6 hours per acre in 1993 to less than 3 hours in 2011 (**Figure 2.27**). This change is consistent with the changes in equipment size, tillage practices used, and productivity. Strong adoption of reduced tillage and no-till has reduced the trips across the field while larger tractors and combines have decreased the time to cover an acre. Improved yields have only added to these efficiency gains over time. Over the past 20 years corn farmers have reduced their investment in time to produce an acre of corn by roughly 11 minutes per year.

See **Figures 2.32 and 2.33** for more detail regarding corn implied labor hours results on a regional basis.

Cotton Lint

Cotton producers have seen considerable reductions in the amount of time it takes to produce cotton for many reasons. 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 continual trend toward less intensive tillage has cut the hours spent tilling and planting. As with all crops the size and speed of harvesting equipment has led to reduced time in the field and recent technology of on-board modeling cotton harvesters stands to reduce the harvest time even more. The implied hours to produce an acre of cotton has decreased from about 11 hours per planted acre in 1990 to less than 4 hours in 2011.today (**Figure 2.28**).

See **Figures 2.34 and 2.35** for more detail regarding cotton lint implied labor hours results on a regional basis.

Rice

The implied labor to produce an acre of rice has decreased by roughly one-third, averaging about 6 hours per acre in 2011 (**Figure 2.29**). On a per unit production basis, the implied labor is 5.6 minutes per cwt. There is little if any abandonment of planted acreage given that all rice is irrigated and complete crop failure is rare. Improved application of irrigation water, along with increased equipment size over time, has helped continue the trend in labor efficiency, cutting per acre labor by 15 minutes per acre per year.

See **Figures 2.36 and 2.37** for more detail regarding rice implied labor hours results on a regional basis.

Soybeans

The implied labor to produce an acre of soybeans declined from 4.3 hours per acre in 1993 to 1.9 hours in 2011 (**Figure 2.30**). On a per bushel basis, soybeans labor dropped from 0.131 hours per bushel (7.4 minutes) to 0.046 hours (2.7 minutes). The trend for soybeans data prior to 1993 are counterintuitive to expectations and cannot be explained by actions being taken on the farm as they imply that the hours per planted acre increased by nearly 2 hours in the late 1980s. The shift appears to be a change in the categorization of the data but the USDA was not able to give an explanation and any attempt would be speculation.

USDA data on the paid and unpaid labor hours used to produce soybeans implies a continued upward trend in the time invested to produce soybeans in the Mississippi Portal region. The trend is not consistent with trends seen in soybean production in other growing regions of the U.S. A review of the underlying factors that would support this trend indicate that the region sees a greater incidence of tillage for establishment of their soybean crop than other regions, measured by tillage passes in the USDA ARMs data. The Mississippi Portal region also sees a somewhat higher incidence of cultivation for weed control than in other regions. These factors appear to explain at least part of the difference in the Mississippi Portal's labor investment but don't fully explain the upward trend in labor.

See **Figures 2.38 and 2.39** for more detail regarding soybeans implied labor hours results.

Wheat

The implied labor hours to produce an acre of wheat or a bushel of wheat have both declined over the period 1990 through 2011 (**Figure 2.31**). The hours per acre have declined from 2.7 hours to 2.0 hours, a 26% reduction, while the hours per bushel have declined from 0.085 hours (5 minutes) to 0.054 hours (3.24 minutes). The reduction in implied labor to produce a bushel or acre of wheat has not fallen as much over time as other crops such as corn, soybeans, or rice, but the absolute amount of labor used to produce wheat has historically been relatively low on a per acre basis. The primary cause of inherently low labor per acre for wheat growers is due to the very large equipment. Lack of progress on a per bushel basis is more attributed to relatively slow yield gains over time, averaging 0.85% per year. Wheat production technology and seed development seem to have had a greater focus on quality and milling characteristics than yield. Another factor that impacts the yield number on a planted acre basis is the relatively high implied abandonment level for wheat and has averaged 0.15 over the period compared with other grain crops with levels above 0.02. Several factors combine to cause the low ratio of harvested to planted area including wheat planted as a soil conserving cover, wheat planted for pasture, and wheat being traditionally grown in drought prone areas. Field to Market is not aware of any data that exist that would allow us to correct for these factors.

Please note, in the graphs below, the regression equations and R^2 values for each line graph are provided. In the regression equations for these analyses, X is always the coefficient with respect to time; the X values are 1 (year 1), 2 (year 2) and so on. The X coefficient has the unit of the appropriate Y axis. The R^2 value explains the degree of correlation between the dependent variable Y and the independent variable X. A high R^2 value (close to 1) indicates that there is a strong correlation with respect to time, e.g., a trend.

See **Figures 2.40 and 2.41** for more detail regarding wheat implied labor hours results on a regional basis.

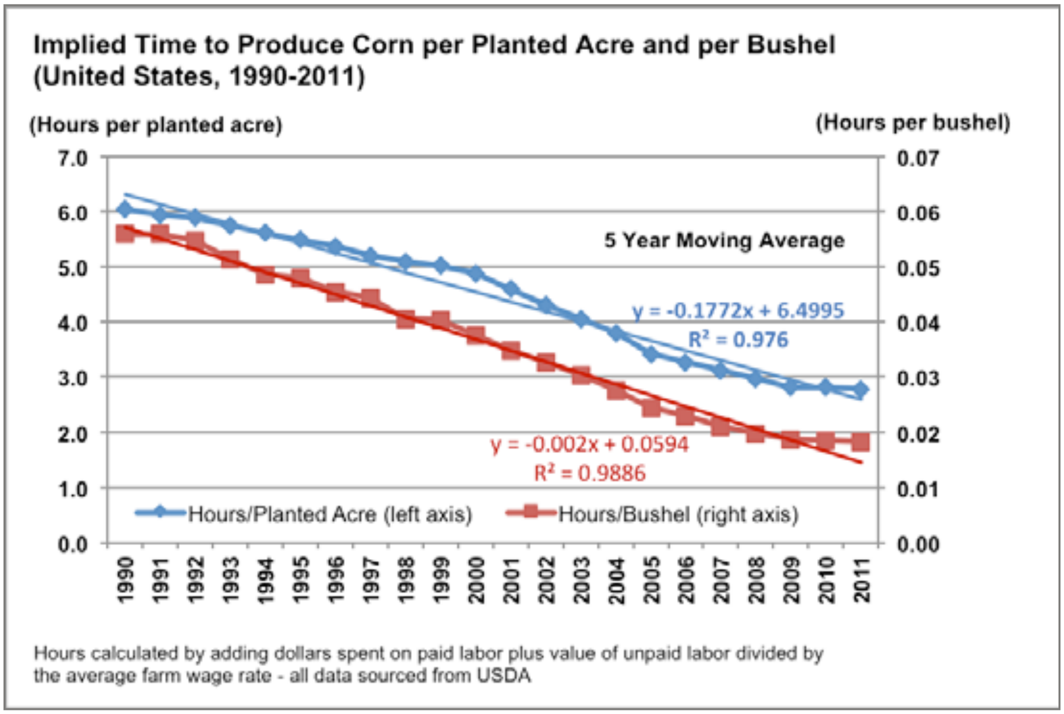


Figure 2.27 Implied Time to Produce Corn per Planted Acre and per Bushel, United States 1990-2011

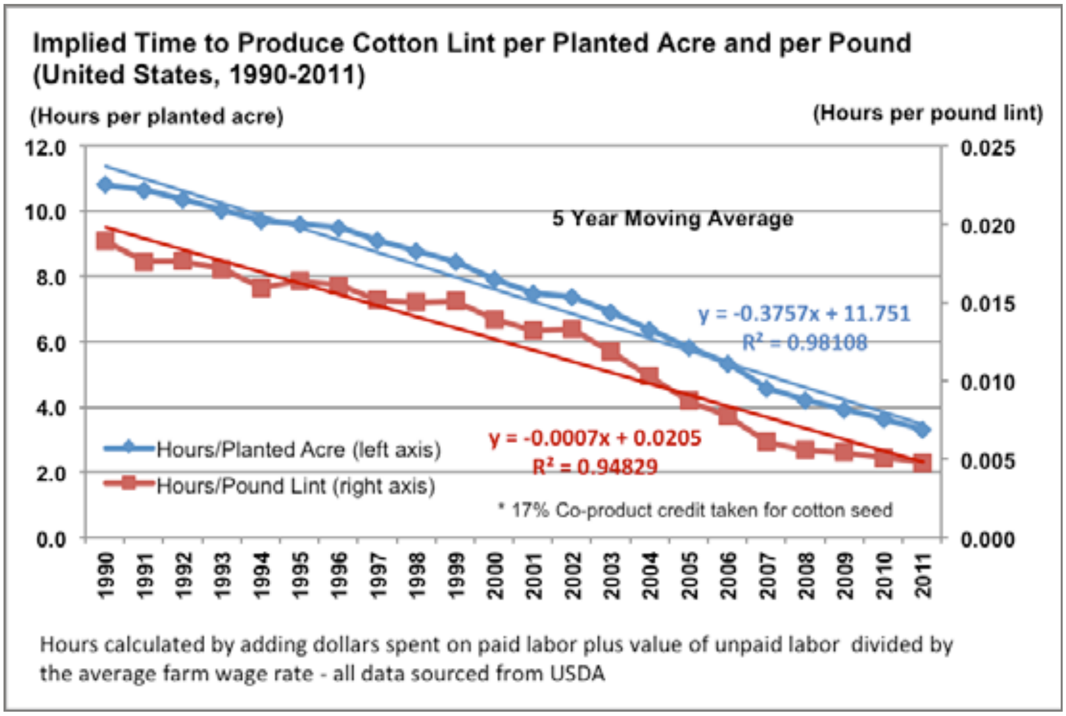


Figure 2.28 Implied Time to Produce Cotton Lint per Planted Acre and per Pound, United States 1990-2011

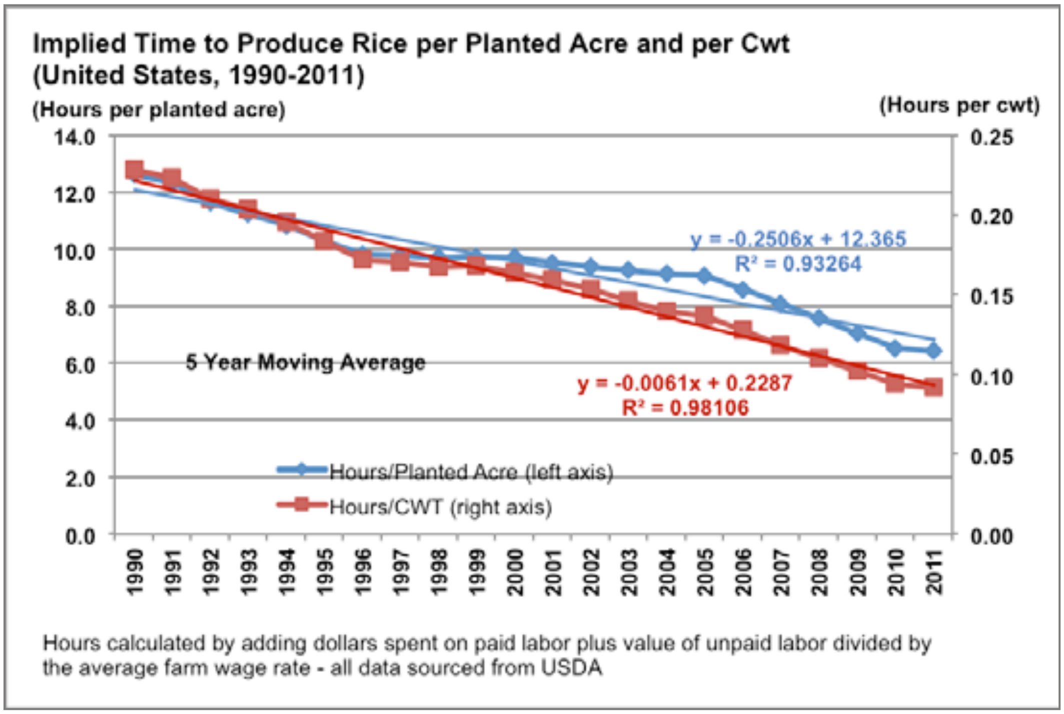


Figure 2.29 Implied Time to Produce Rice per Planted Acre and per Cwt, United States 1990-2011

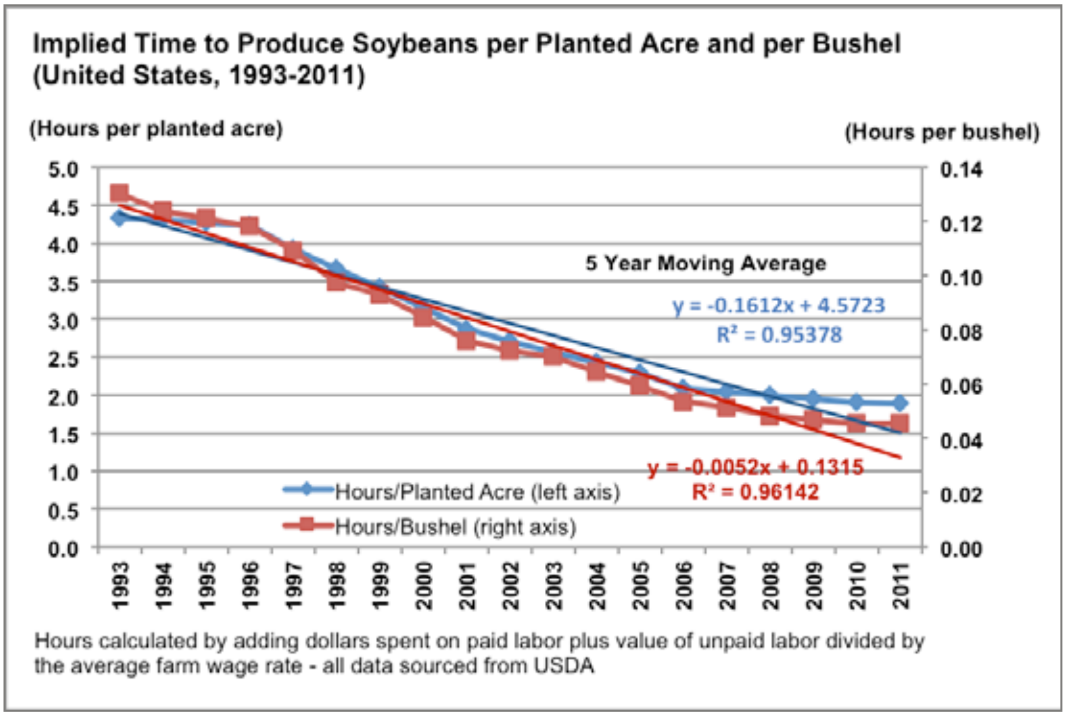


Figure 2.30 Implied Time to Produce Soybeans per Planted Acre and per Bushel, United States 1993-2011

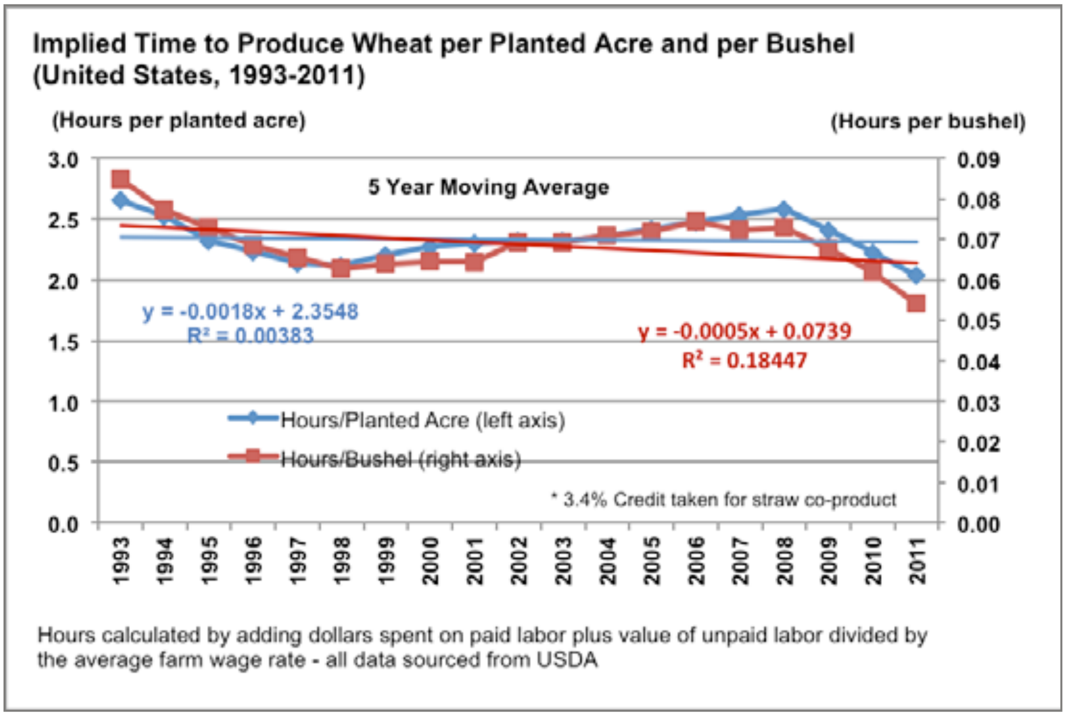


Figure 2.31 Implied Time to Produce Wheat per Planted Acre and per Bushel, United States 1993-2011

Regional Implied Labor Hours

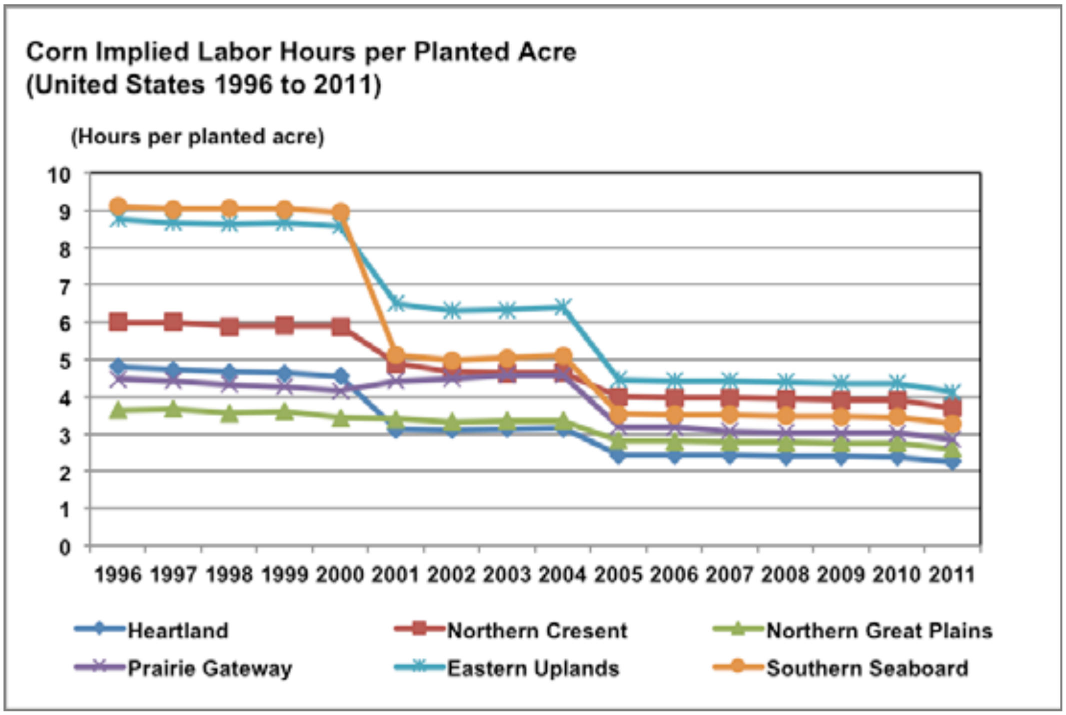


Figure 2.32 Corn Implied Labor Hours per Planted Acre by Region, United States 1996-2011

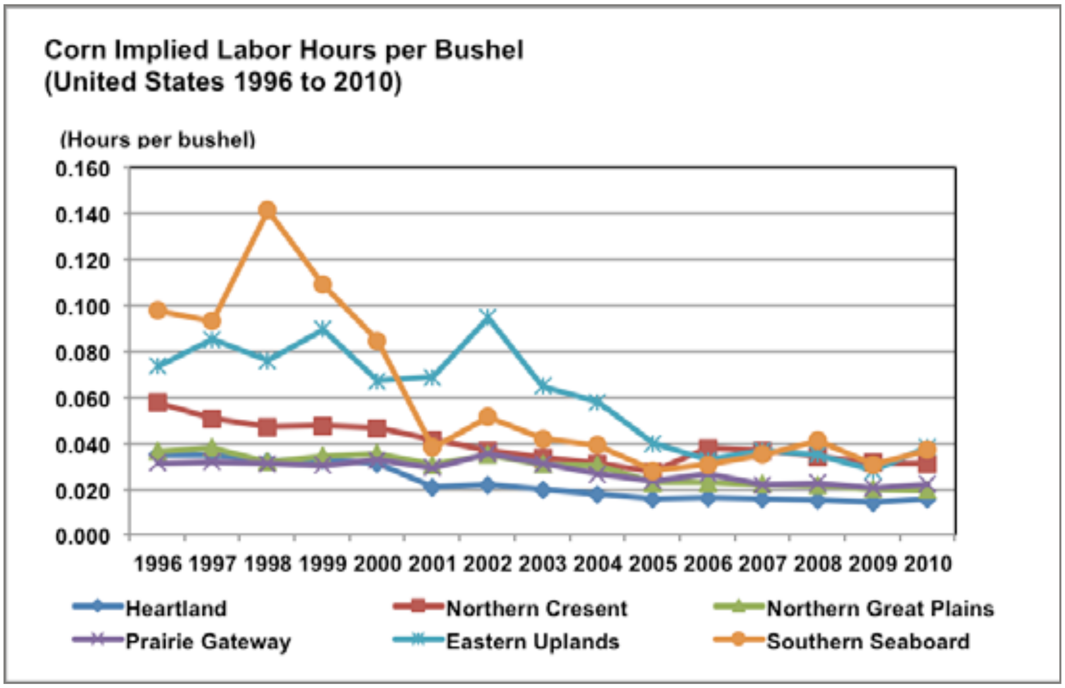


Figure 2.33 Corn Implied Labor Hours per Bushel by Region, United States 1996-2010

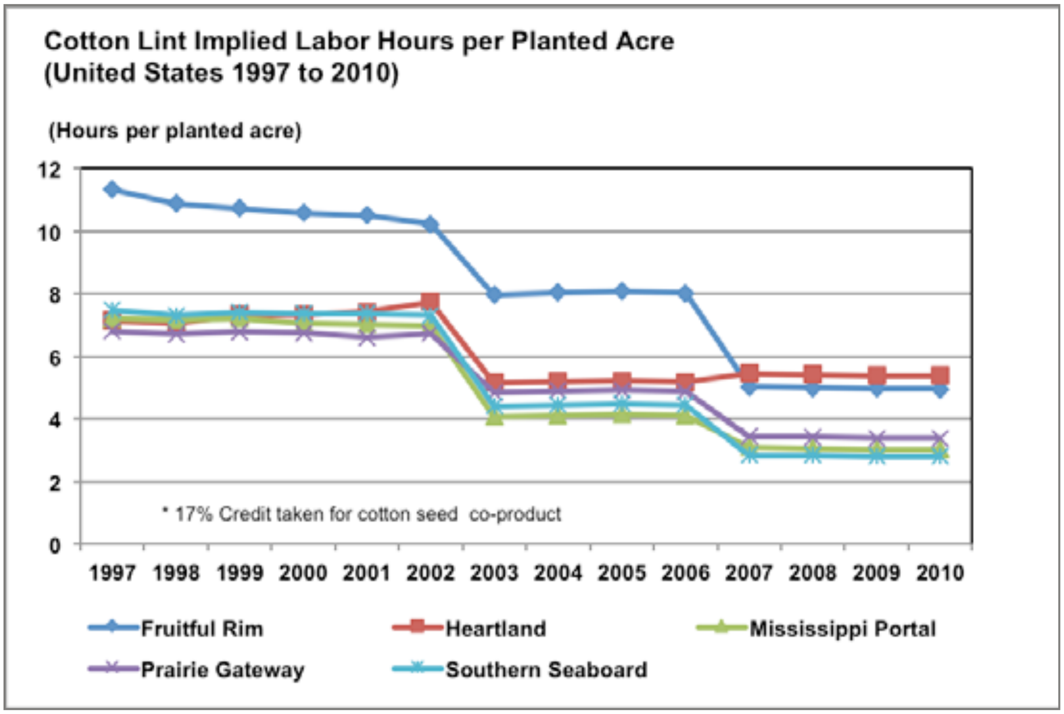


Figure 2.34 Cotton Lint Implied Labor Hours per Planted Acre by Region, United States 1997-2010

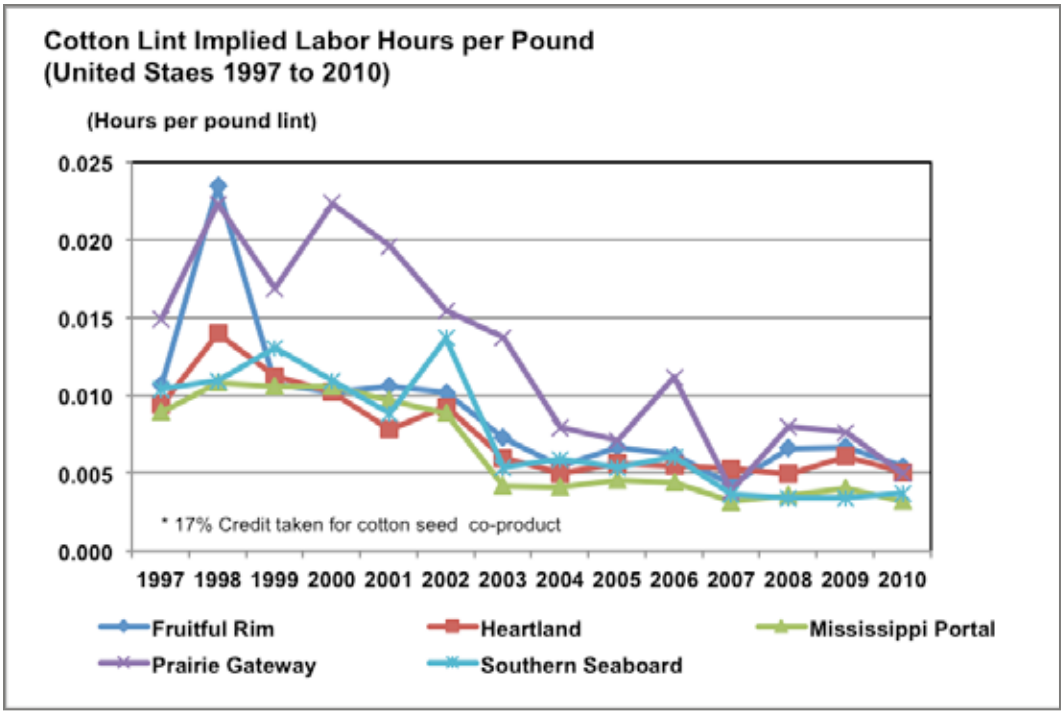


Figure 2.35 Cotton Lint Implied Labor Hours per Pound by Region, United States 1997-2010

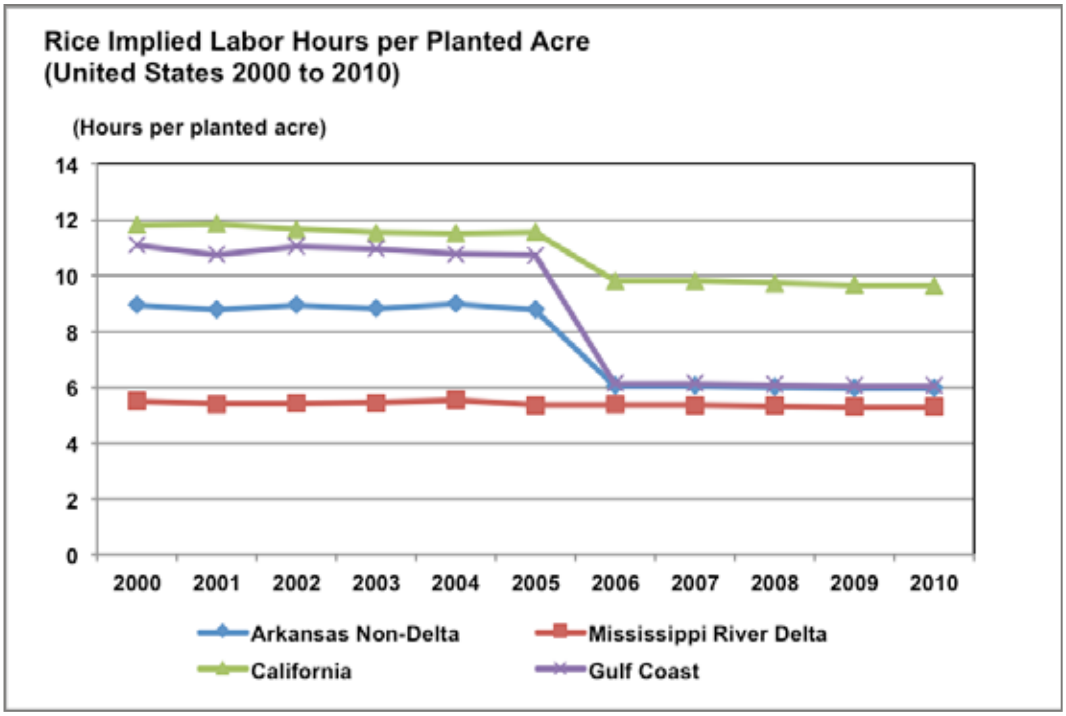


Figure 2.36 Rice Implied Labor Hours per Planted Acre by Region, United States 2000-2010

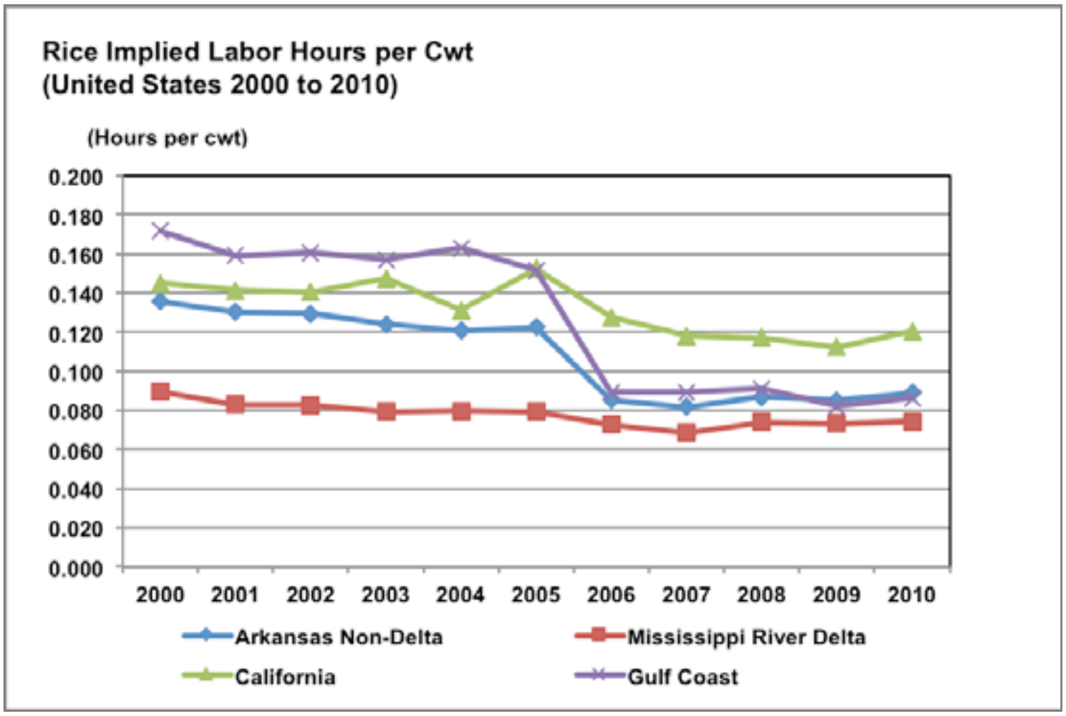


Figure 2.37 Rice Implied Labor Hours per Cwt by Region, United States 2000-2010

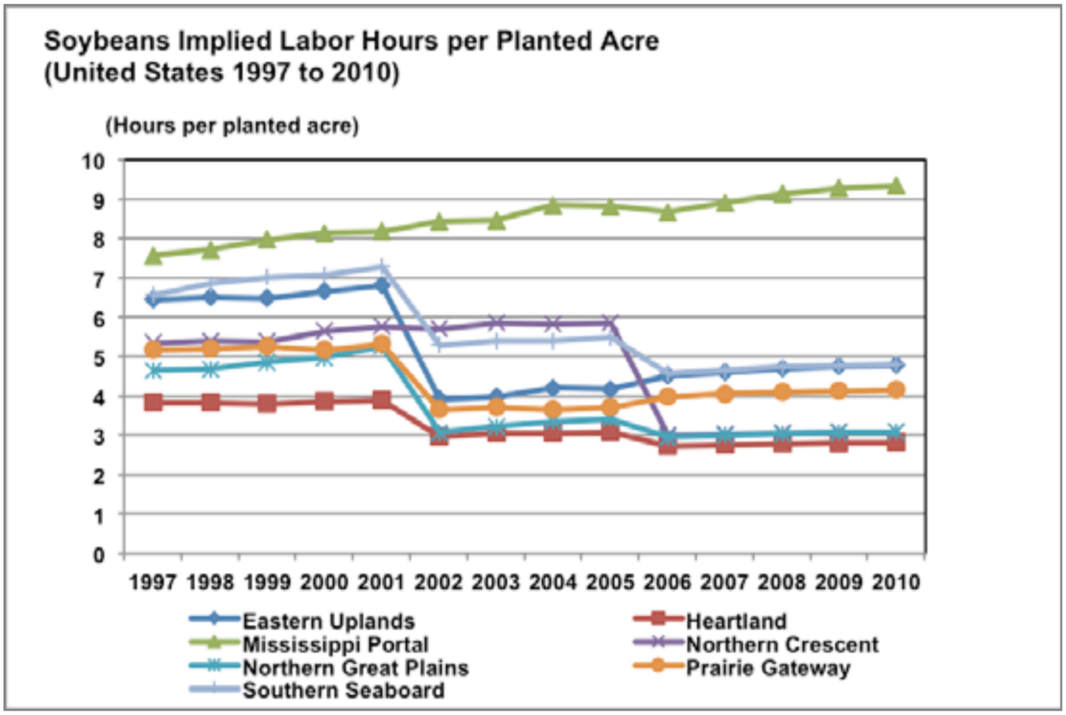


Figure 2.38 Soybeans Implied Labor Hours per Planted Acre by Region, United States 1997-2010

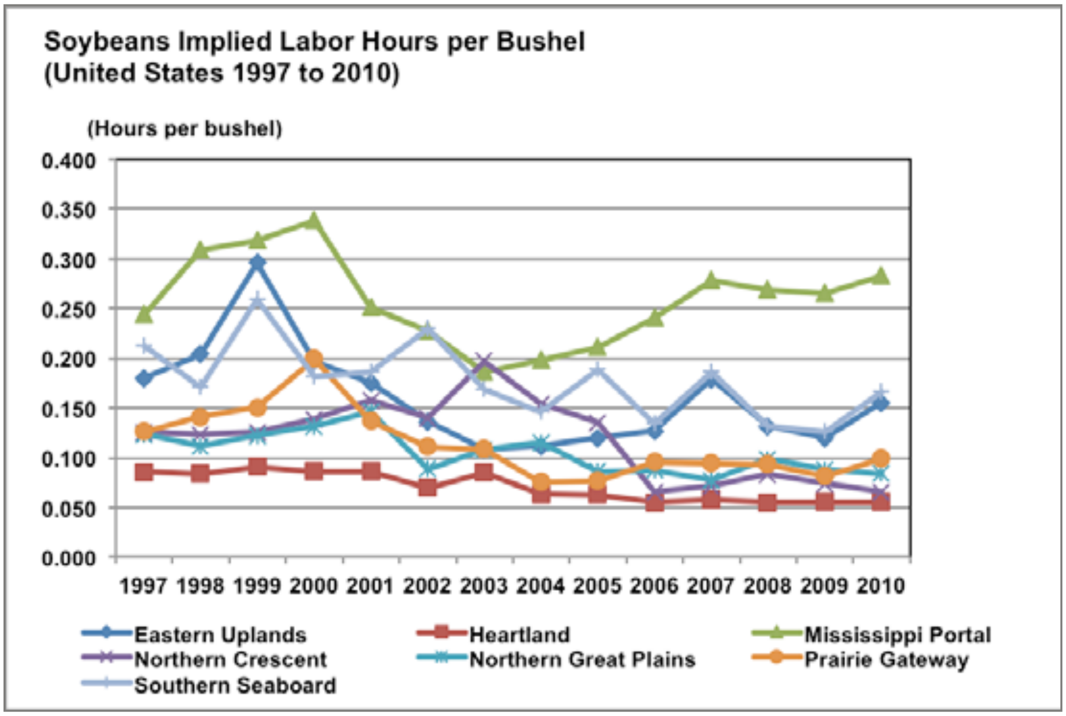


Figure 2.39 Soybeans Implied Labor Hours per Bushel by Region, United States 1997-2010

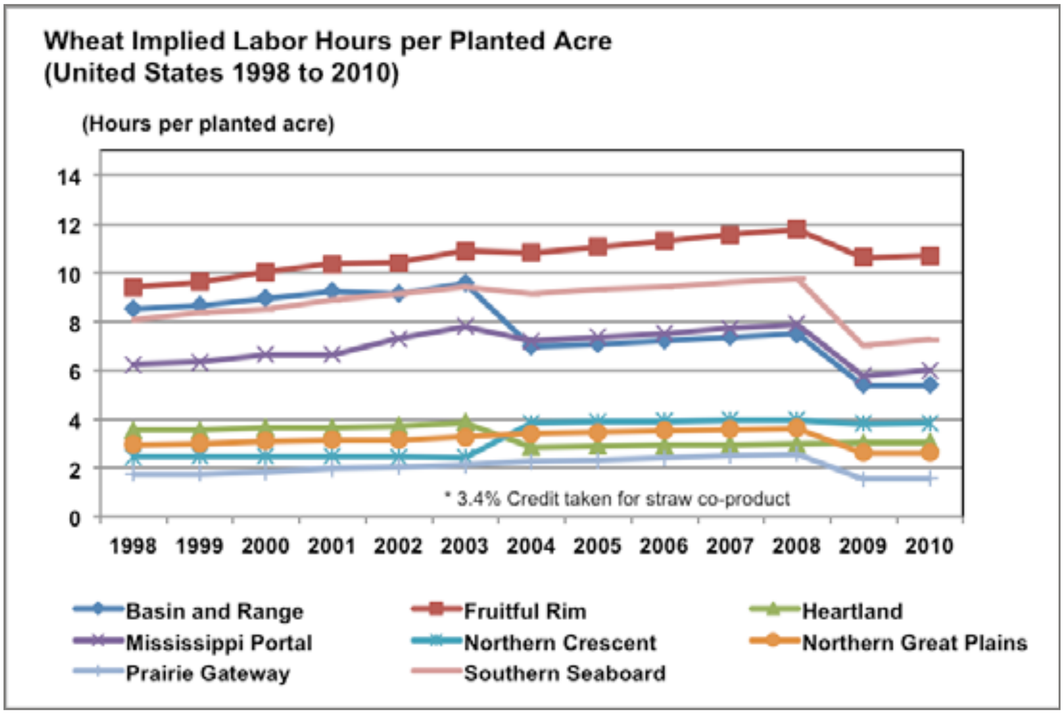


Figure 2.40 Wheat Implied Labor Hours per Planted Acre by Region, United States 1998-2010

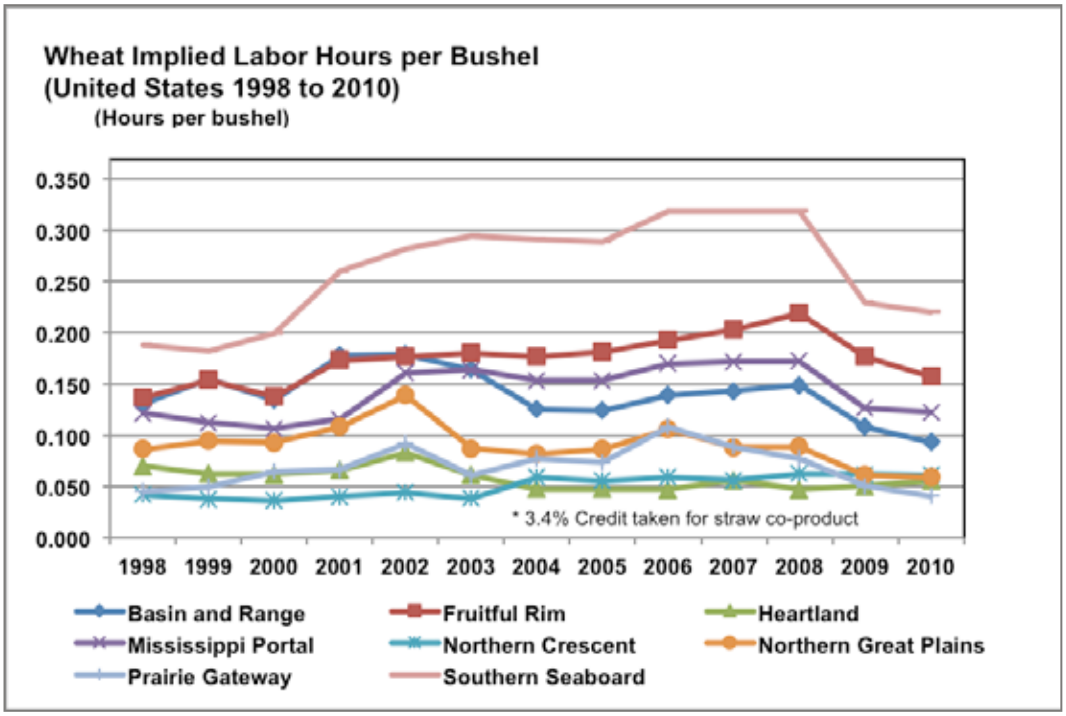


Figure 2.41 Wheat Implied Labor Hours per Bushel by Region, United States 1998-2010

4. Socioeconomic Indicators Investigated But Not Included

4.1 Introduction

The socioeconomic indicators contained in this section were explored but determined inappropriate for inclusion at this time for various reasons detailed in each indicator section, below. Many indicators were not selected because other indicators provided a better representation of the desired outcome. In other cases, national datasets were not available at all, or over an extended time period. Some were excluded due to definitional or directional ambiguity, or due to lack of significant correlation with actions being taken on the farm.

Other indicators were not included because of USDA ERS farm type classifications. For many surveys, farm types are determined by those having value of production of 50% or more from a particular activity and therefore skewed data by crop type. In addition, in these surveys, cotton is included with tobacco and peanut and cannot be broken out by specific crop type.

4.2 Household Income

The well-being of farm operator households is not equivalent to the financial performance of the farm sector or of farm businesses because there are other stakeholders in farming, such as landlords and contractors. In addition, farm operator households have non-farm investments, jobs, businesses, and other links to the nonfarm economy that are separate from their farming interests. Primarily for this reason, household income was not included as an indicator in this report. Crop type for this data is also determined by those having value of production of 50% or more from a particular activity, therefore providing a highly variable farm-type designation over time.

4.3 Real Gross Revenue per Acre

Gross revenue is revenue minus the costs of goods sold. The uncertainties of weather, yields, prices, government policies, global markets, and other factors can cause wide swings in farm income.

Data were investigated based on the USDA's Agricultural Resource Management Survey. This indicator was deemed to be a component of the recommended indicator "returns above variable costs" and therefore is not presented separately. In addition, price volatility could contribute to a false trend.

4.4 Cropland Value

Production value of land reflects its ability to provide consumers with goods and services through the extraction of minerals or organic goods as food and fiber. This value aligns with the notion that property value comes from the combination of land, labor, capital and management to produce something that people will pay for and generating income for the property owners. Value is used for the sale of the land and the calculation for capital gains.

Data were investigated based on the USDA's Agricultural Resource Management Survey, are only available at the state level and are not crop specific. This indicator was deemed to be a component of the recommended indicator "returns above variable costs" and therefore not needed for economic demonstration.

4.5 Total Factor Productivity

Total factor productivity (TFP) is the portion of output not explained by inputs used in the production process. As such, it could be determined by technology growth, efficiency, weather, etc.

USDA data on agricultural TFP is estimated at national and state levels, not by farm enterprise type. It is difficult to identify the factors contributing to the TFP growth relevant to the USDA data provided and therefore the indicator was not included.

4.6 Cash Flow, Input Costs, and Costs of Funds

Data were investigated based on the USDA's Agricultural Resource Management Survey, are only available at the state level and are not crop specific. This indicator was deemed to be a component of the recommended indicator "returns above variable costs" and therefore not needed for economic demonstration.

4.7 Poverty Rate

Threshold for poverty in the general economy may not be appropriate for farm specific areas given the non-monetary benefits that may occur on a farm, including food and housing as part of worker compensation.

4.8 Education – Farmer

Farmers should have access to the most recent information on techniques and efficiencies of food production. Improving knowledge of new techniques and technologies – in addition to providing with any physical resources necessary for implementation – can dramatically increase the farmers' level of productivity.[112]

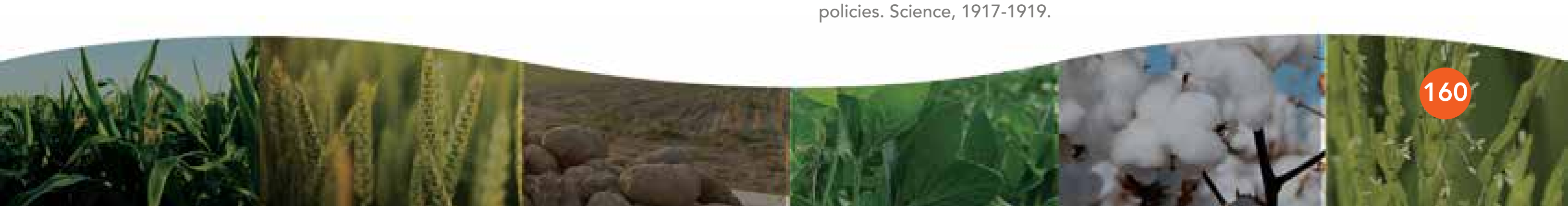
Data were investigated based on the USDA's Agricultural Resource Management Survey, which is subject to the 50% farm value designation described above. A primary reason for exclusion of this indicator is that education level is heavily influenced by geographic and larger community/demographic trends rather than by crop type or other factors specific to actions taken within the farm gate.

4.9 Education – Community

Education can be measured by the number of school years completed, number of persons completing high school and college, functional literacy rates, and participants in adult education. Education is important to the community as it provides members of a farm-based community improved chances for success in complex modern farming as well as in other types of professional career fields.

Data investigated on community-wide education level for agriculture communities wer based on the USDA's Agricultural Resource Management Survey, and were not presented for this report as data are geographic, not crop specific, and farmers do not directly control access to or participation in education by the community as a whole.

[112] Rosegrant, M. & Cline, S. 2003. Global food security: Challenges and policies. Science, 1917-1919.



4.10 Succession Planning

Farm succession planning is the process of transferring the farm intact to the next generation of their family. Farm succession planning is crucial to the long term success of the farm because it unlocks cash from the organization for the exiting generation of owners and creates an atmosphere in which the next generation can begin taking over.

Data were investigated based on the USDA's Agricultural Resource Management Survey and were not as robust as needed for a complete analysis. However, this indicator is considered an important social indicator and may be included if better data become available in the future.

4.11 Land Ownership and Land Tenure

Farm tenure refers to the share of land of a farming operation that is owned by the operation. Each farming operation must have access to assets in order to produce crop and livestock products. This access may be obtained through renting rather than outright ownership.

Data were investigated based on the USDA's Agricultural Resource Management Survey. This indicator was not included because of a lack of directional context as renting or owning does not always have an impact on sustainable farm management practices and whether one is preferred over the other is largely a value judgment.

4.12 Healthcare Insurance

Healthcare insurance is insurance against the risk of incurring medical expenses among individuals.

Data were investigated based on the USDA's Agricultural Resource Management Survey. This indicator was not included because of the differing ways healthcare insurance can be acquired that are not directly controlled by the farm operator. For example, spouses who work off-farm may insure the entire family through their workplace.

4.13 Farm Labor Practices/Child Labor Practices

Hired farmworkers make up less than one percent of all U.S. wage and salary workers, but they play an essential role in U.S. agriculture. Their wages and salaries represent roughly 17 percent of total variable farm costs, and as much as 40 percent of costs in labor intensive crops such as fruits, vegetables, and nursery products. Hired farmworkers continue to be one of the most economically disadvantaged groups in the United States.

Child labor refers to the employment of children at regular and sustained labor. This practice is considered exploitative by many international organizations and is illegal in many countries. Child labor laws in the United States set the minimum age to work in an establishment without restrictions and without parents' consent at age 16, except for the agricultural industry where children as young as 12 years of age can work in the fields for an unlimited number of non-school hours.

Both hired labor and child labor are recognized as important social issues; however, commodity crops, the focus of this study, have different labor characteristics than specialty crops, which are more aligned with migratory workers issues. Regarding child labor, many commodity farms are family farms that employ family members and are therefore not recognized as formal child labor.

4.14 Incidence Levels of Foodborne Illness

Foodborne illness is caused by consuming contaminated foods or beverages. Many different disease-causing microbes, or pathogens, can contaminate foods, so there are many different foodborne infections. In addition, poisonous chemicals, or other harmful substances can cause foodborne diseases if they are present in food.

Foodborne illness is recognized as a significant issue but is more common when discussing specialty crops rather than commodity crops, which are the focus of this study.

4.15 Biosecurity Protection Against Transmission of Zoonotic Diseases

Biosecurity is a strategic and integrated approach encompassing policies, regulations, tools, and activities to ensure food safety, as well as animal and plant life and health. Biosecurity concerns include: the introduction of plant pests, animal pests and diseases, zoonosis, threats to biodiversity, the introduction and management of invasive alien species and genotypes, and the protection of the environment.

Biosecurity protection against transmission of zoonotic diseases is recognized as a significant issue but is more common when discussing specialty crops rather than commodity crops, which are the focus of this study.

5. Conclusions and Discussion

This report does not define a benchmark level for socioeconomic indicators but rather explores broad-scale progress over time related to the major challenges facing agriculture in the twenty-first 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 are needed in complement to analyses of environmental outcomes, especially as they may help us to better evaluate the sustainability implications of various trends in markets and production practices, e.g., larger yields, 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.

A review of a limited number of indicators is provided in this report in order to address the social and economic concerns of sustainable agriculture under the direct control of the farmer that contribute to the success and well-being of the farmer, farmer household, and farming community.

The social indicators 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 the reduced amount of tractor hours and therefore the reduced amount of operator labor hours needed. The incorporation and improvement of GPS equipment and precision agriculture technologies, including improved safety mechanisms for both old and new equipment, have also contributed to the decrease in worker injury due to operator fatigue.

The economic indicators are driven in part by farming costs and revenues. While economics are affected by a multitude of variables in the agricultural industry – including food and nutrition and food safety policy, macro and micro economic trends, and federal support mechanisms –farmers have more direct control over their costs than revenues and continuously seek the optimal use of all inputs.

The main issues contributing to the omission of many socioeconomic metrics in this report are data availability challenges such as gaps in data continuity, definitional ambiguity, and data relevance to commodity crop farming. In many instances available data are not crop specific, the metric is not significantly under the control of the farm operator, and/or meaningful conclusions cannot be derived. In addition, USDA ARMS classifies farm types by criteria of a grower receiving over 50% of gross income coming from specific crop activity. Therefore the accounting of crop specific farms experiences volatility due to variations of product pricing. For example, many farmers switch between soybeans and corn production depending upon price fluctuations of those respective crops. Finally, cotton is typically included with tobacco and peanuts and cannot be broken out by specific crop type.

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 hope and 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.