

Disrupters to Fertilizer Industry Golden Era: Too much demand and too much scrutiny

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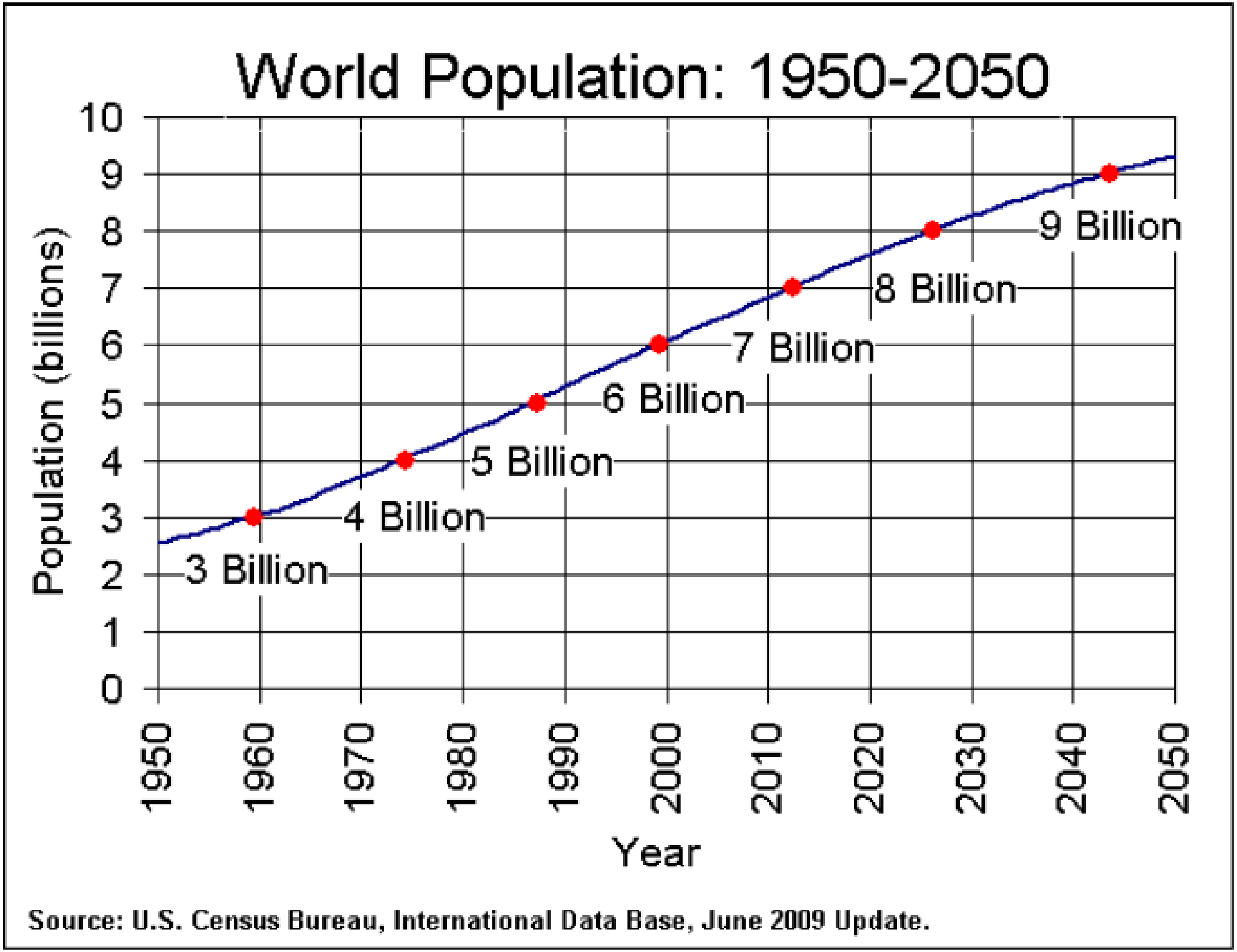
Consultative Group for International Agricultural Research


World Population: 1950-2050
10
9
8
7
6
5
4
3
2
1
0
Population (billions)
9 Billion
8 Billion
7 Billion
6 Billion
5 Billion
4 Billion
3 Billion
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Source: U.S. Census Bureau, International Data Base, June 2009 Update.

Brave New World Since 2005

- Rapid, sustained economic growth in the most populous developing countries
- Rapid rise in petroleum prices
- Convergence of energy and agriculture
- Falling supply relative to demand for staple food prices

Urban-industrial expansion onto prime farmland at the periphery of Kunming (+6 million), the capital of Yunnan Province, China,

Photo: K.G. Cassman

Clearing virgin rain forest in Brazil: powerful +feedback to GHG emissions

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- Falling supply relative to demand for staple food prices
- **Little progress to reduce poverty and malnutrition**

Food insecurity: unsustainable crop production on marginal land by poor farm families without other options

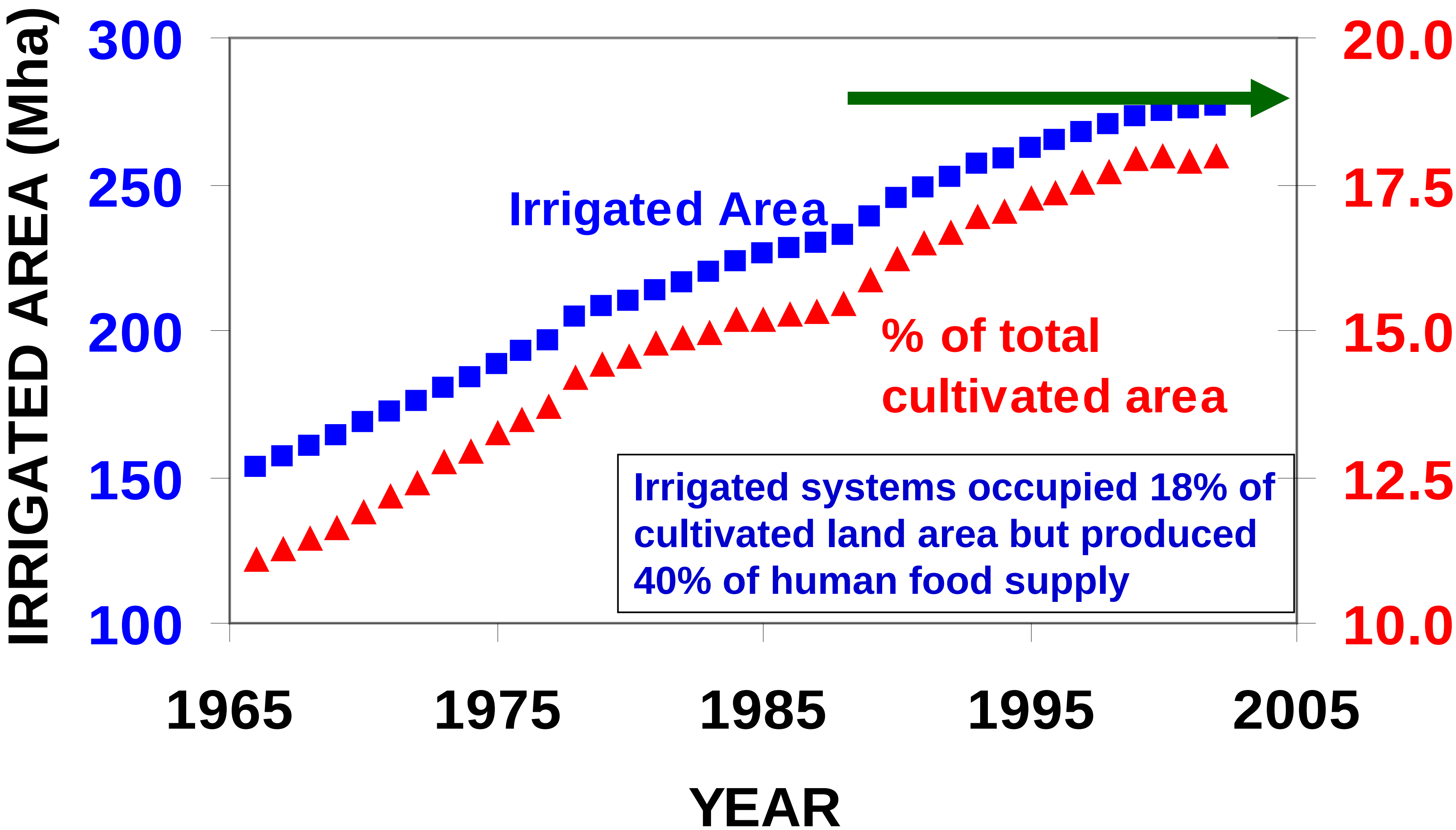
Photo: K.G. Cassman


Photo: K.G. Cassman

Brave New World Since 2005

- Rapid, sustained economic growth in most populous developing countries
- Rapid rise in petroleum princes
- Convergence of energy and agriculture
- Smaller supply, relative to demand, of staple food crops; steep rise in the price of these foods
- Little progress to reduce poverty and malnutrition
- **Limited supplies of good quality arable land and accessible fresh water**
- **Stagnating yields in some of the most productive cropping systems**
- **Increasing concerns about environment and climate change**

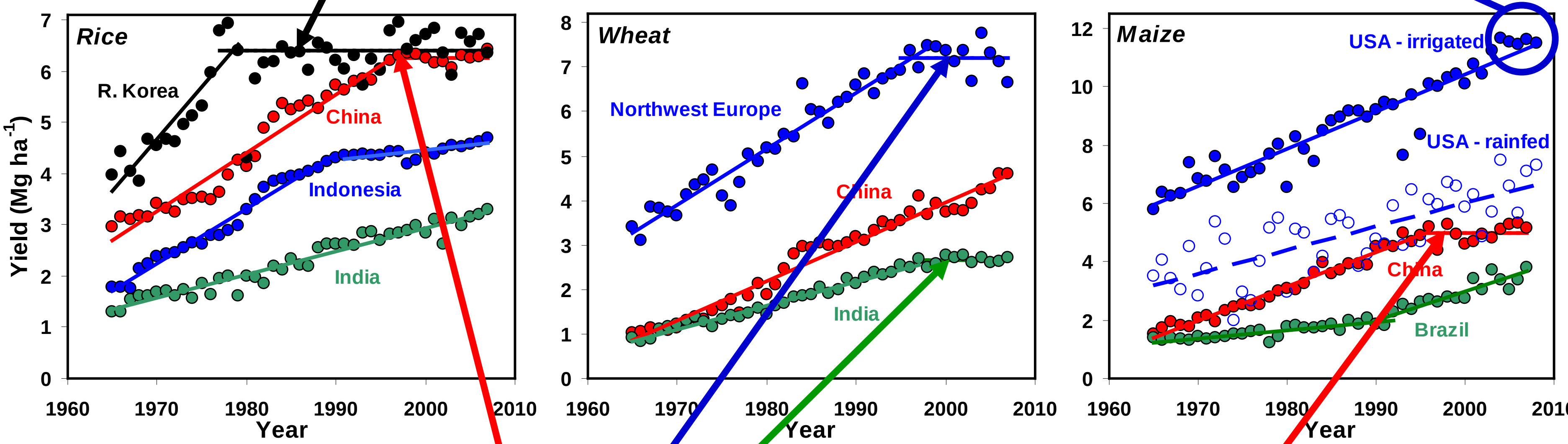
Global Irrigated Area and as a % of Total Cultivated Land Area, 1966-2004



Stagnating yields for RICE in Korea, Japan, and China; WHEAT in northwest Europe and India; MAIZE in China, and IRRIGATED MAIZE in the USA.

Cassman, 1999. PNAS, 96: 5952-5959

Grassini et al., 2011. FCR 120:142-152



Cassman et al., 2003, ARER 28: 315-358

Cassman et al., 2010, Handbook of Climate Change

Brave New World Since 2005

- **Rapid, sustained economic growth in most populous developing countries**
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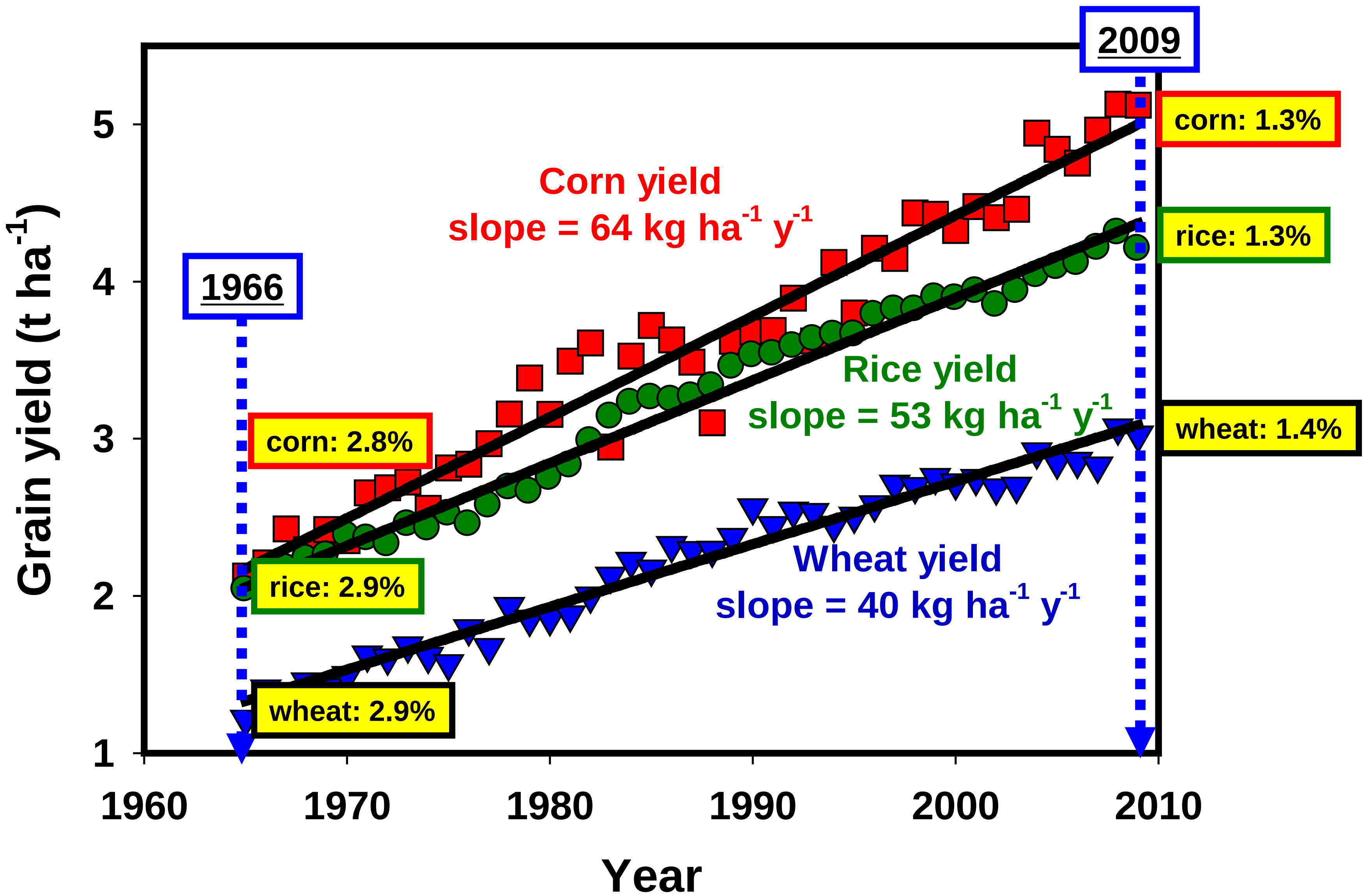
- **Increasing poverty and malnutrition**
- **Limited supplies of good quality arable land and accessible fresh water**
- **Stagnating yields in some of the most productive cropping systems**
- **Increasing concerns about environment and climate change**
- **These are likely to be LONG-TERM MEGATRENDS**

Global Cereal Yield Trends, 1966-2009
(tyranny of linear growth rates)



Source: FAOSTAT

Assuming a goal of no net expansion of current crop production area……

- **A ~60% increase in cereal* yields needed by 2050 (39 yr) = 1.54% yr^{-1} of current average yield**
- **Business as usual will not meet 2050 global demand for food, feed, fuel in without large expansion of crop area**
- **How much help from less meat and less post-harvest losses and food waste?**

***Cereals for food, feed, fuel, bio-industrials**

The Challenge is Clear

- Increase food supply +70% (cereals + 60%) on existing crop and pasture land
- Substantially decrease environmental footprint of agriculture
  - Protect water quality and conserve water for non-agriculture uses
  - Maintain or improve soil quality
  - Reduce greenhouse gas emissions
  - Protect wildlife and biodiversity
- Called “sustainable intensification”

A Golden Age for Fertilizer Industry?

- **Increased yields and removal of grain and biomass requires greater nutrient uptake (more commercial fertilizer)**
- **But fertilizer efficiency is very low is most places; efficiency gains will make net increase in fertilizer use less than increase in yields (but still a substantial increase)**
- **Increasing concerns about environmental impact of agriculture will place greater pressure on documenting environmental performance of fertilizer use, and perhaps also increasing regulations**

Three Disruption Stories

- Greenhouse gas emissions from corn-ethanol life cycle (2006-2009)
- Recent EPA report on Integrated Nitrogen Management (2011 release)
- High yield, high efficiency, low global warming intensity, irrigated corn in Nebraska (2012)

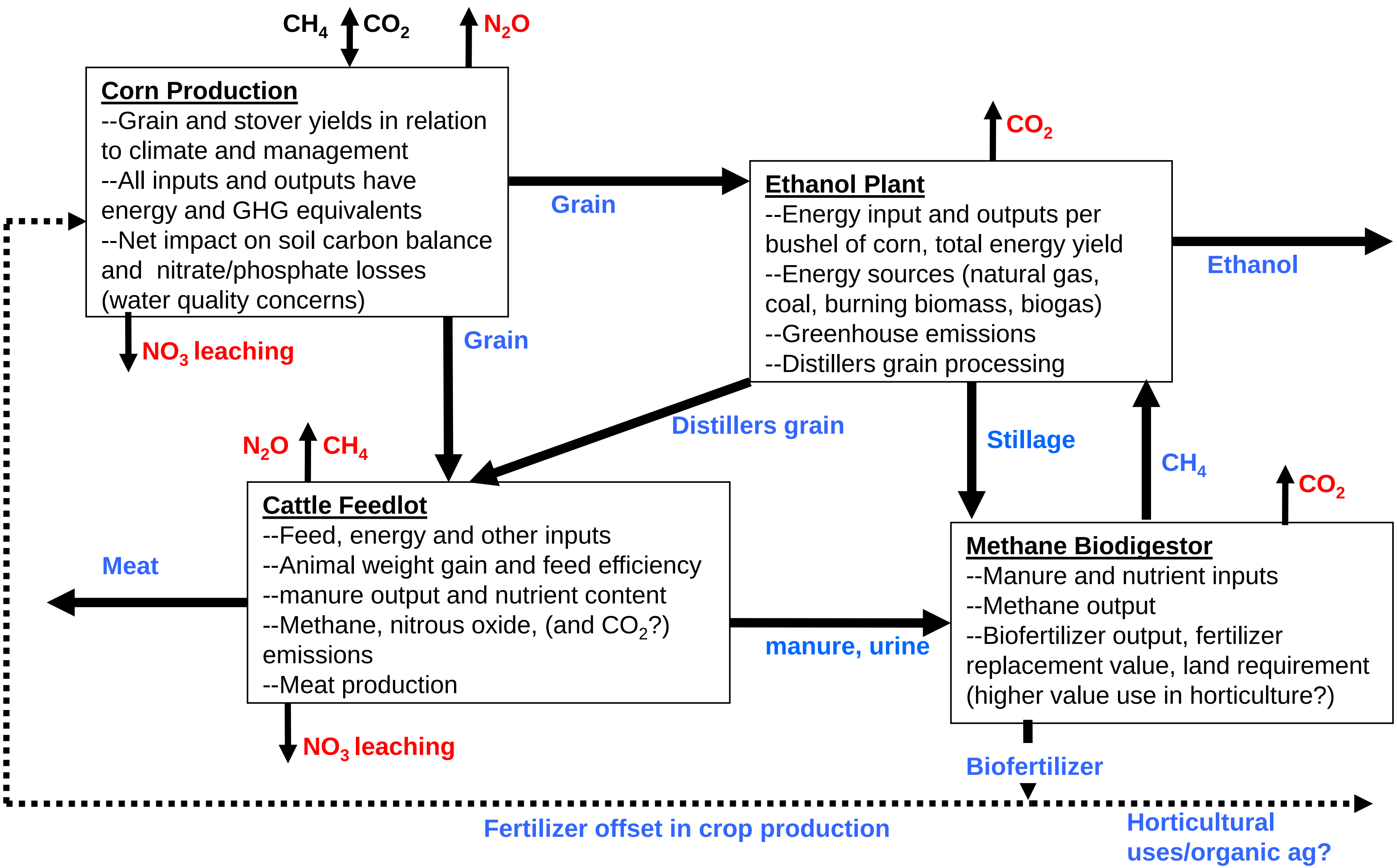
Biofuels Case Study: from good guy to villain in 2-years: 2005 to 2007

- **Benefits**
  - **Decreased reliance on imported petroleum**
  - **Net reduction in greenhouse gas (GHG) emissions**
  - **Rural jobs and economic development**
  - **Reduces cost of gasoline for consumers ($25-80B/yr)**
- **Negative impacts and concerns**
  - **Relies on subsidies**
  - **Net increase in GHG emissions and net energy loss (energy inputs > outputs)**
  - **Uses too much water, causes land use change**
  - **Major cause of rising food prices**

2007 EISA definition: Life Cycle GHG Emissions

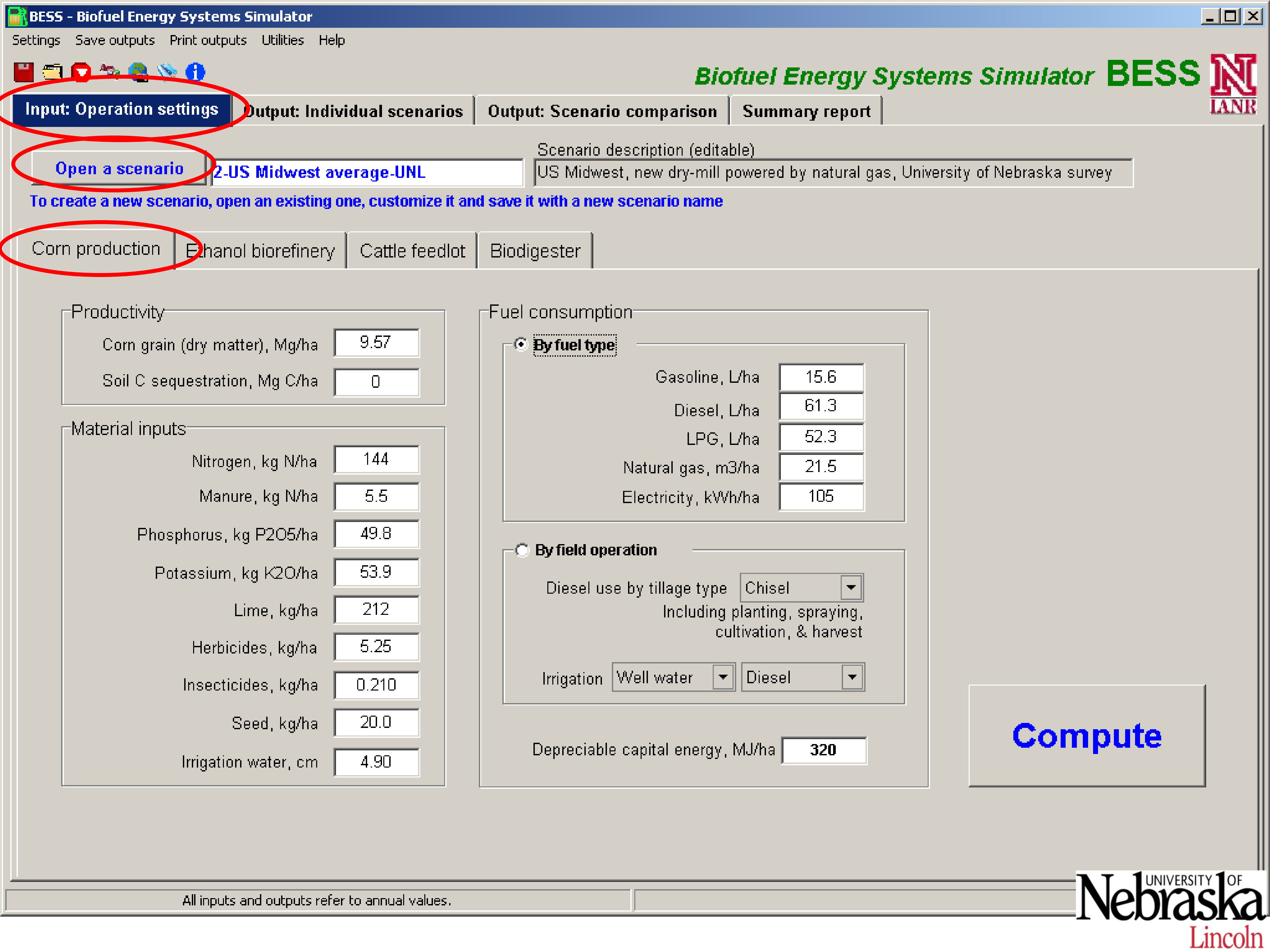
''(H) LIFECYCLE GREENHOUSE GAS EMISSIONS.—The term 'lifecycle greenhouse gas emissions' means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential.

Life Cycle Assessment: Integrated Biofuel Biorefinery with Corn Grain as Feedstock



Biofuel Energy Systems Simulator (BESS) [available at: www.bess.unl.edu]

- Most up to date estimates for direct-effect GHG emissions for corn ethanol based on best current science and input from all key disciplines (engineers, agronomists, soil scientists, animal nutritionists, industry professionals)
- User-friendly, completely transparent, and well documented
- Default scenarios based on regional-scale data, but can also be used for certification of an individual ethanol plant, its associated corn supply and co-product use
- Can be used for estimating carbon-offset credits for emissions trading with an individual ethanol plant as the aggregator
- If GREET can be consistent with BESS for corn-ethanol GHG emissions estimates, then BESS can be used for compliance and certification


BESS - Biofuel Energy Systems Simulator
Settings
Save outputs
Print outputs
Utilities
Help
Biofuel Energy Systems Simulator BESS
IANR
Input: Operation settings
Output: Individual scenarios
Output: Scenario comparison
Summary report
Open a scenario
2-US Midwest average-UNL
Scenario description (editable)
US Midwest, new dry-mill powered by natural gas, University of Nebraska survey
To create a new scenario, open an existing one, customize it and save it with a new scenario name
Corn production
Ethanol biorefinery
Cattle feedlot
Biodigester
Productivity
Corn grain (dry matter), Mg/ha 9.57
Soil C sequestration, Mg C/ha 0
Material inputs
Nitrogen, kg N/ha 144
Manure, kg N/ha 5.5
Phosphorus, kg P2O5/ha 49.8
Potassium, kg K2O/ha 53.9
Lime, kg/ha 212
Herbicides, kg/ha 5.25
Insecticides, kg/ha 0.210
Seed, kg/ha 20.0
Irrigation water, cm 4.90
Fuel consumption
By fuel type
Gasoline, L/ha 15.6
Diesel, L/ha 61.3
LPG, L/ha 52.3
Natural gas, m3/ha 21.5
Electricity, kWh/ha 105
By field operation
Diesel use by tillage type
Chisel
Including planting, spraying, cultivation, & harvest
Irrigation
Well water
Diesel
Depreciable capital energy, MJ/ha 320
Compute
All inputs and outputs refer to annual values.
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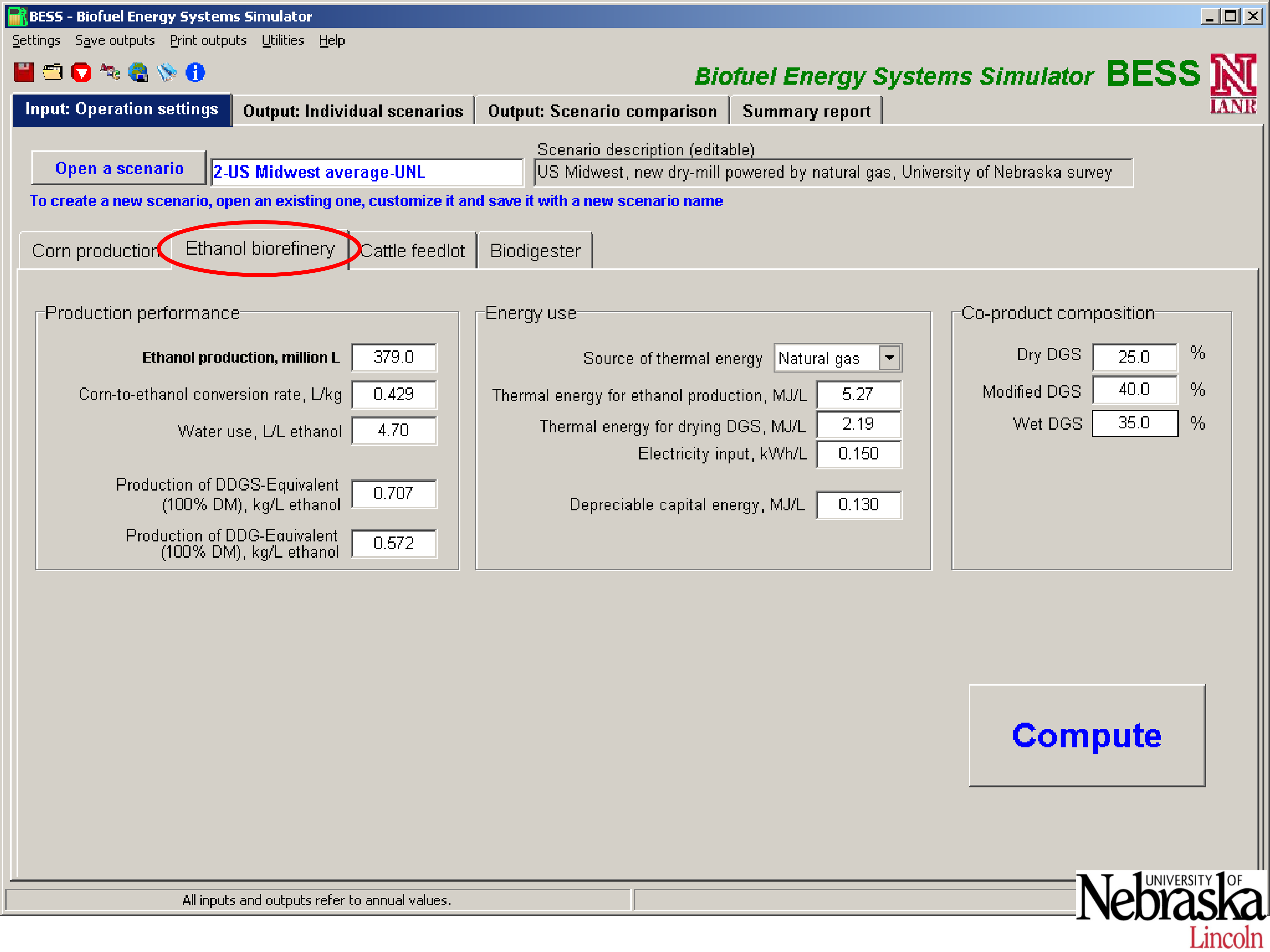
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Corn production
Ethanol biorefinery
Cattle feedlot
Biodigester
Production performance
Ethanol production, million L 379.0
Corn-to-ethanol conversion rate, L/kg 0.429
Water use, L/L ethanol 4.70
Production of DDGS-Equivalent (100% DM), kg/L ethanol 0.707
Production of DDG-Equivalent (100% DM), kg/L ethanol 0.572
Energy use
Source of thermal energy Natural gas
Thermal energy for ethanol production, MJ/L 5.27
Thermal energy for drying DGS, MJ/L 2.19
Electricity input, kWh/L 0.150
Depreciable capital energy, MJ/L 0.130
Co-product composition
Dry DGS 25.0 %
Modified DGS 40.0 %
Wet DGS 35.0 %
Compute
All inputs and outputs refer to annual values.
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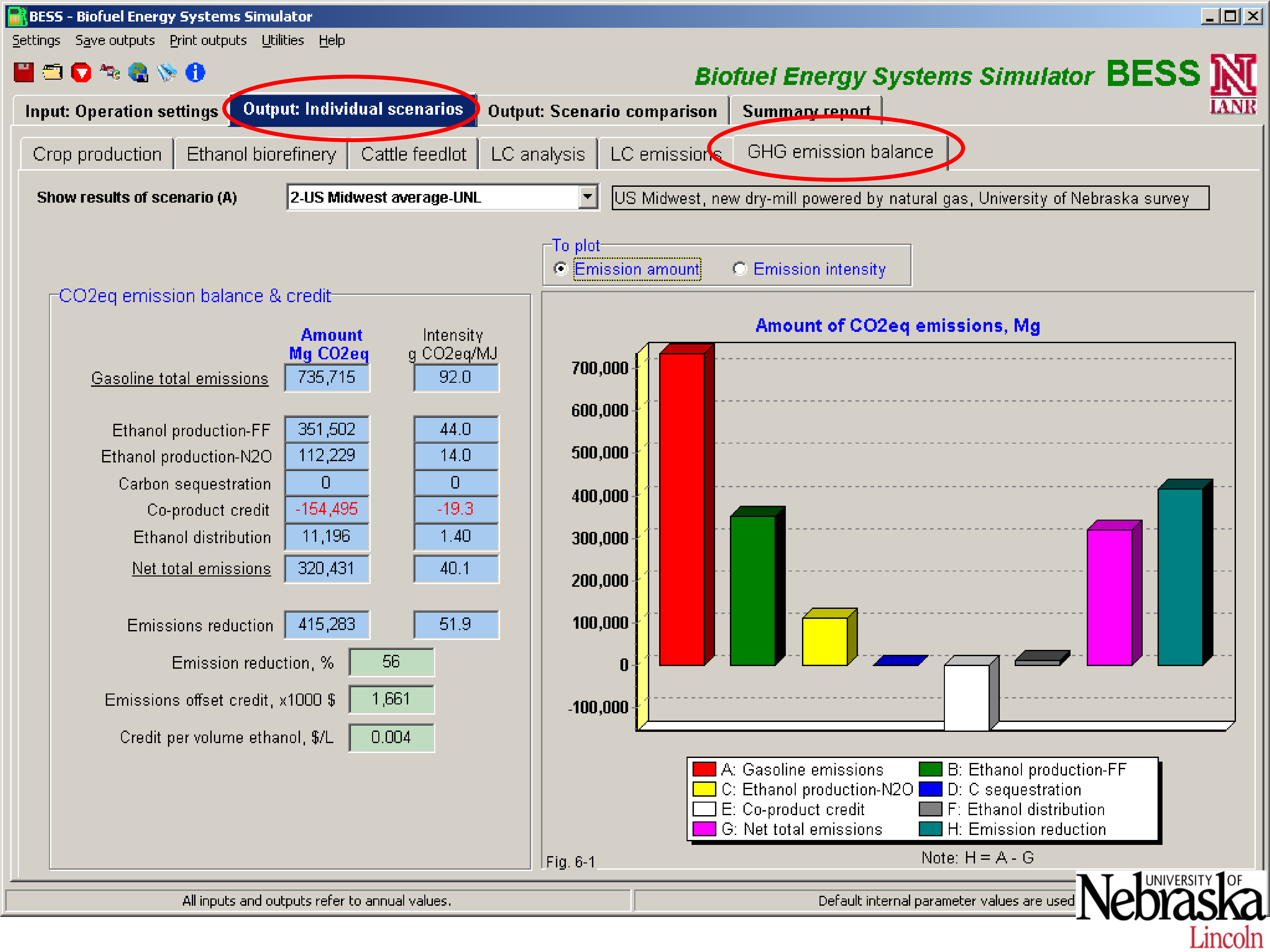
BESS - Biofuel Energy Systems Simulator
Settings Save outputs Print outputs Utilities Help
Biofuel Energy Systems Simulator BESS
IANR
Input: Operation settings
Output: Individual scenarios
Output: Scenario comparison
Summary report
Crop production
Ethanol biorefinery
Cattle feedlot
LC analysis
LC emissions
GHG emission balance
Show results of scenario (A)
2-US Midwest average-UNL
US Midwest, new dry-mill powered by natural gas, University of Nebraska survey
To plot
Emission amount
Emission intensity
CO2eq emission balance & credit
Amount Mg CO2eq
Intensity g CO2eq/MJ
Gasoline total emissions 735,715 92.0
Ethanol production-FF 351,502 44.0
Ethanol production-N2O 112,229 14.0
Carbon sequestration 0 0
Co-product credit -154,495 -19.3
Ethanol distribution 11,196 1.40
Net total emissions 320,431 40.1
Emissions reduction 415,283 51.9
Emission reduction, % 56
Emissions offset credit, x1000 $ 1,661
Credit per volume ethanol, $/L 0.004
Amount of CO2eq emissions, Mg
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
-100,000
A: Gasoline emissions
B: Ethanol production-FF
C: Ethanol production-N2O
D: C sequestration
E: Co-product credit
F: Ethanol distribution
G: Net total emissions
H: Emission reduction
Fig. 6-1
Note: H = A - G
All inputs and outputs refer to annual values.
Default internal parameter values are used
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Conclusions from BESS analysis

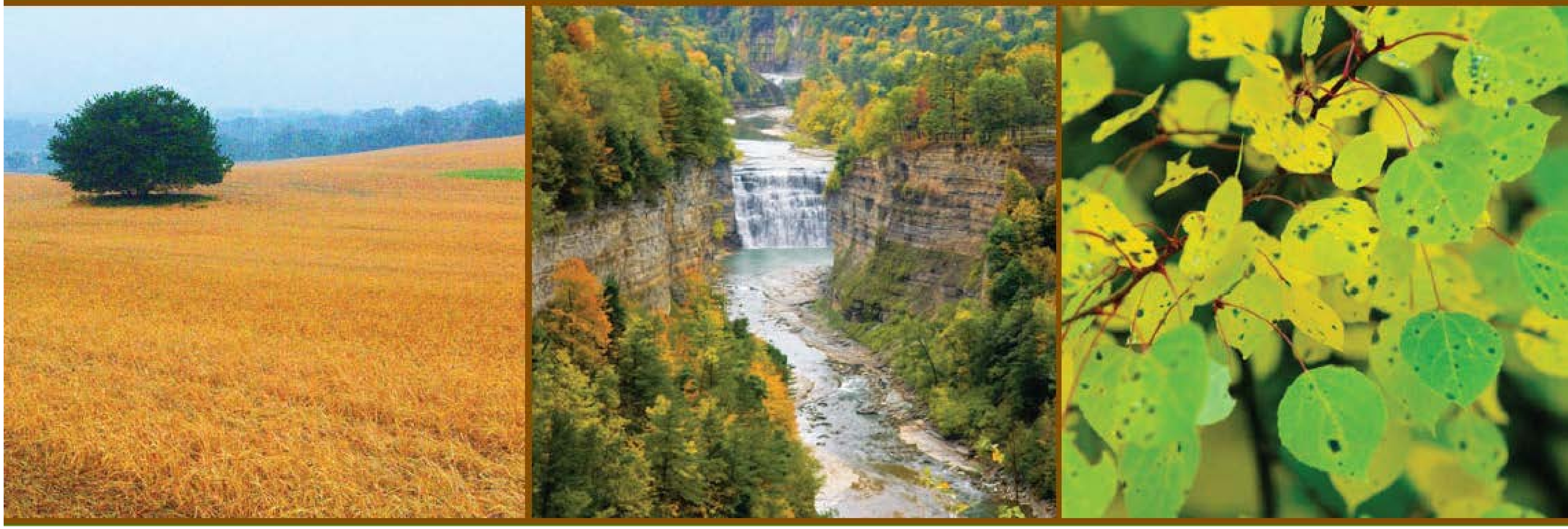
- **Based on state records and recent surveys, natural gas powered dry mills (90% of the industry) can reduce GHG emissions by 48-59% compared to gasoline on average, which is a 2-3 fold greater reduction than reported in previous studies**
- **Crop production represents 42-51% of life-cycle GHG emissions for typical USA corn-ethanol systems; Co-product credits offset 26-38% of life-cycle GHGs**
- **Accurate GHG analysis is essential for enabling ethanol producers to meet the 20% GHG reduction relative to gasoline for the 2007 *EISA*, and will be critical for state-level LCFS**

Published in 2009: Liska AJ, Yang HS, Bremer VR, Klopfenstein TJ, Walters DT, Erickson GE, Cassman KG. Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn-Ethanol. J. Industrial Ecol. 13:58-74

Released: October, 2011

Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options

A REPORT OF THE EPA SCIENCE ADVISORY BOARD



Objectives

- Identify impact of reactive nitrogen (Nr) on the environment and links among the various impacts
- Evaluate impact of integrated N management strategy on environmental impact
- Identify options for EPA to reduce risk of negative environmental impact from Nr
- Make recommendations to EPA about needed research and approaches to reduce risk of negative impact from Nr on environmental services

Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options

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Recommendations

- Because reactive nitrogen (Nr) flows through multiple ecosystems (land, surface and groundwater, estuaries) and in many different forms (NH4, NO3, N2O), new institutional structures are needed for effective control and management
- Requires integrated management that recognizes complex tradeoffs, are cost-effective, and identifies key intervention points
- EPA Intra-agency task force recommended to: (i) better quantify Nr impacts on ecosystems, human health, climate change, (ii) monitoring needs to support informed policies, (iii) identify most efficient and cost-effective ways to reduce Nr volumes and negative Nr impacts on environment, HH, CC.
- Inter-agency task force needed (EPA, USDA, DOE, NSF, DOT, etc) to coordinate "all of government" efforts

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Take Home on EPA Nr Study

- **Nr in form of commercial fertilizer is critical to ensure global food security**
- **There is too much reactive N in the global environment, and it causes degradation of water quality, biodiversity, and has health concerns**
- **Majority of Nr in the environment comes from agriculture**
- **<u>Recommends increased monitoring as basis for mitigation interventions</u>**

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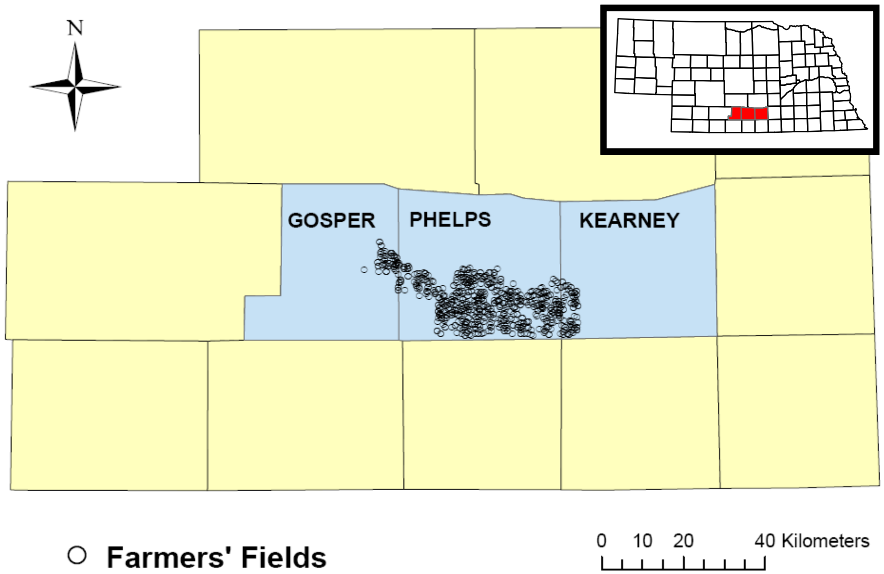
On-farm analysis: maize fields in the Tri-Basin NRD



--- Data from 3 years (2005, 2006, and 2007)
--- 777 field-year data identified with 100% irrigated maize

14 Nov 2012

34° Partly Cloudy
Weather Closings

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Tri-Basin data - with both water use and crop production figures - offered UNL crop and irrigation efficiency researchers everything they needed

Story | Discussion | Image (2)

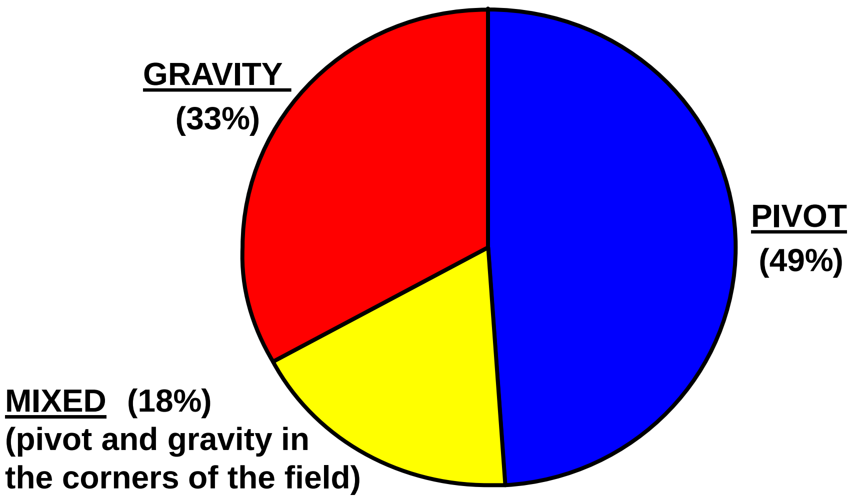
Pivot

Photo by: Lori Potter, Hub file

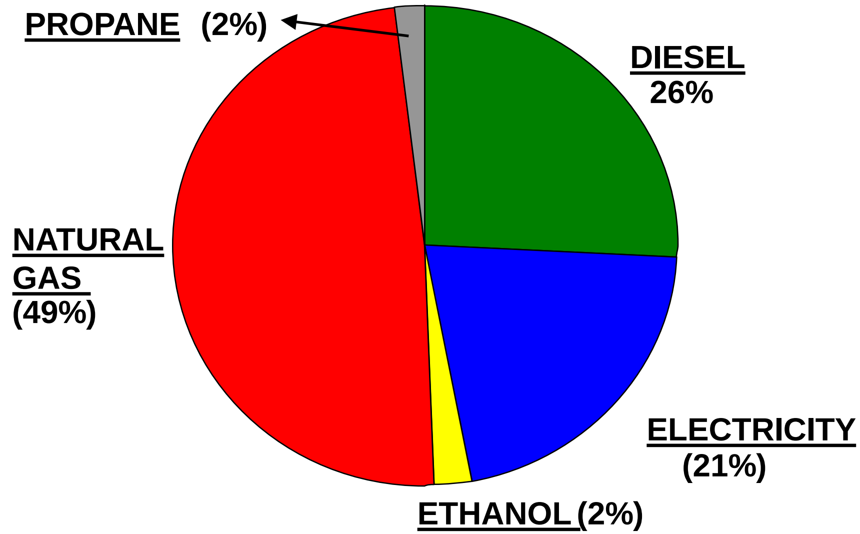
University of Nebraska-Lincoln researchers are using the 2005-2007 crop and water use reports farmers in Gosper, Phelps and Kearney counties submitted to the Holdrege-based Tri-Basin Natural Resources District to study practices and variables affecting the goal of growing more bushels of corn with the same or less irrigation water. A presentation about the study is on the agenda for the Feb. 4 Holdrege Water Conference.

Tri-Basin NRD: irrigation system, rotation, and tillage

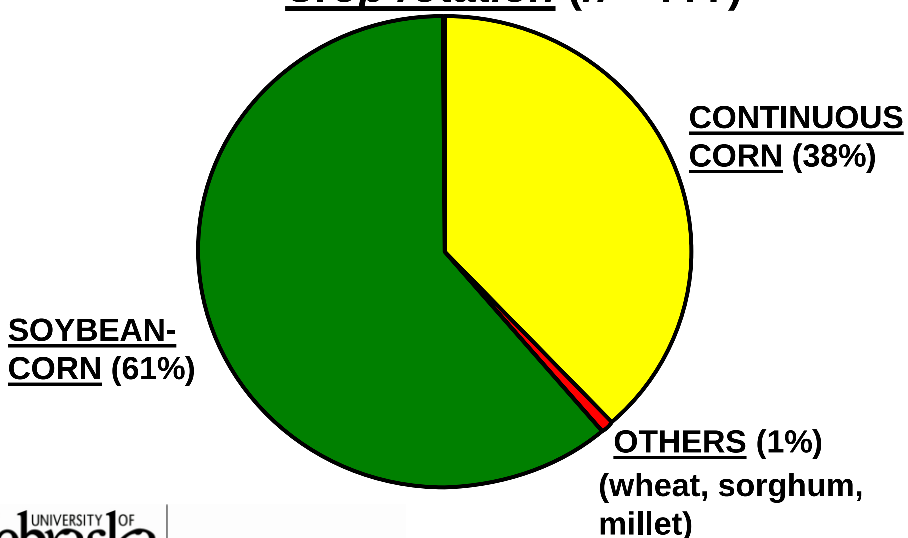
Irrigation system **(*n* = 777)**



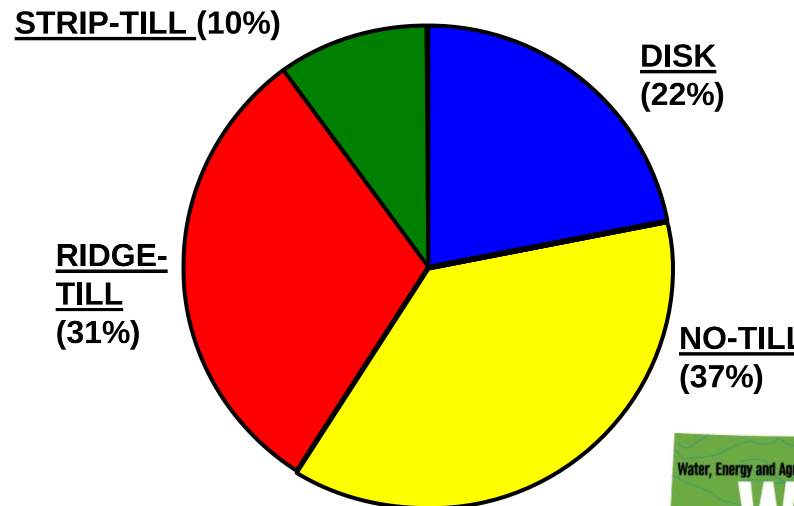
Energy source for irrigation **(*n* = 777)**



Crop rotation **(*n* = 777)**



Tillage system **(*n* = 123)**



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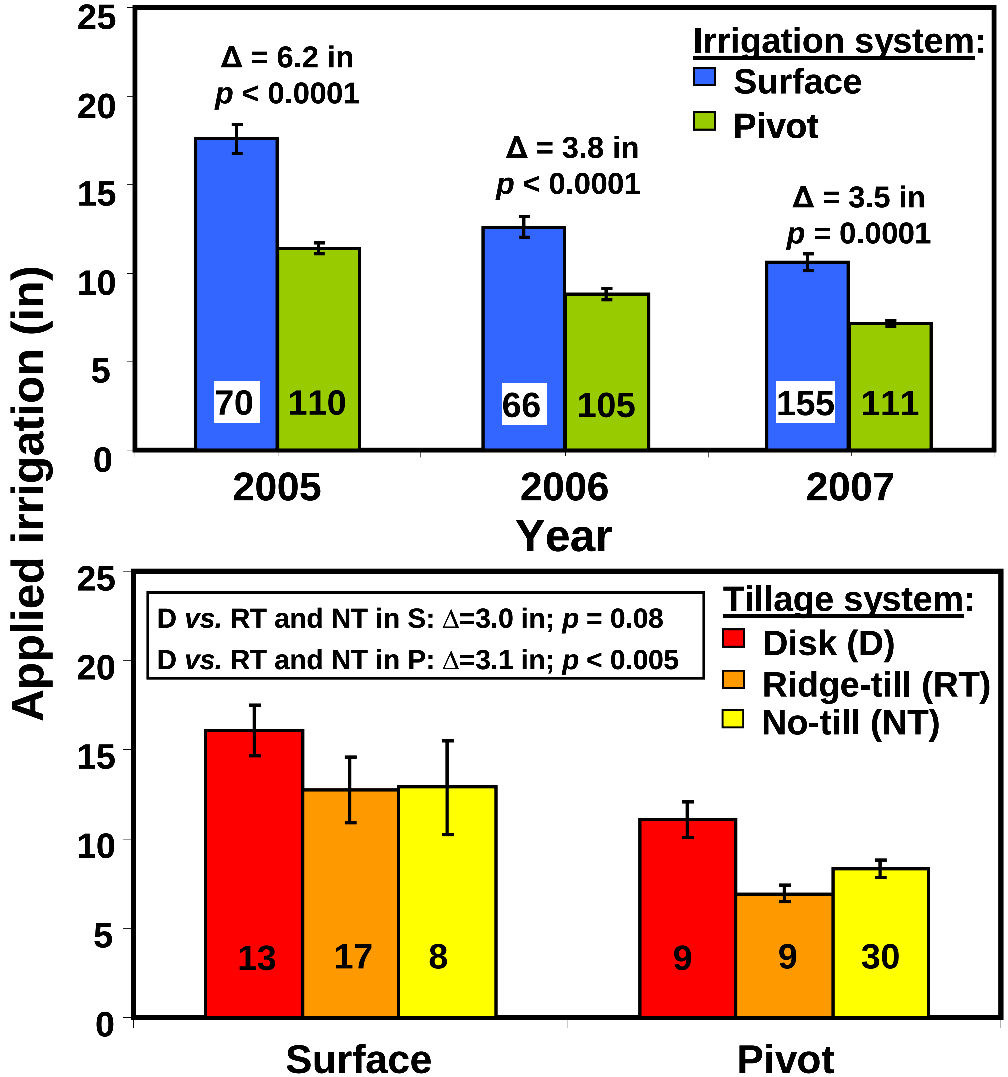
Water, Energy and Agriculture Initiative WEAI

Effect of irrigation system and tillage

* number of observations is indicated inside bars; ** vertical bars indicate ±SE of the mean; *** in the second figure, data were pooled across years. Selected t-test comparisons are shown.



Applied irrigation with pivots was 4.5” less than with surface irrigation. No yield difference!

Applied irrigation under ridge- and no-till was lower than with disk plow (-3.0”)

Modified from Grassini *et al.* (2011): *Field Crops Res.*

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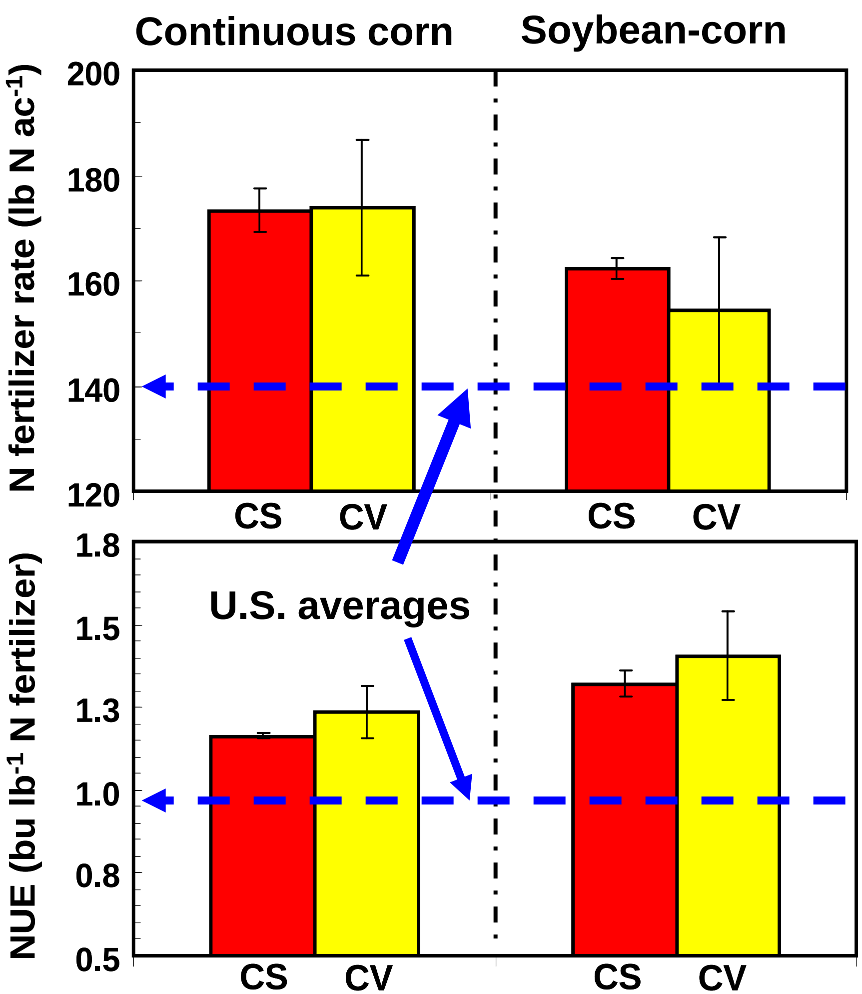
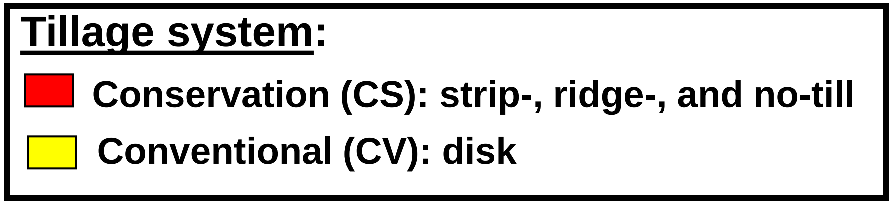
Water, Energy and Agriculture Initiative WEAI

Corn yield, rate of N fertilizer, and nitrogen use efficiency (NUE)*

**** Based on management data collected from 123 fields in the Tri-Basin NRD during 2005-2007 seasons. Values above bars indicate average corn grain yield (bu ac^{-1}) for each rotation x tillage combination***





- **Despite high yields (212 bu/ac average, or 13 metric tons/ha)……….**
- **And, although N rate is above U.S. average, yields and NUE are higher especially under soybean-corn rotation due to higher yields and lower N rate than continuous corn.**
- **No difference in N fertilizer rate under continuous corn with CS or CV tillage; under soybean-corn rotation, N fertilizer tended to be higher under CS than CV.**

Modified from Grassini *et al.* (2011): *Field Crops Res.*

Grain yield, energy yield and efficiency, and greenhouse gas (GHG) emissions from maize production in Nebraska

Crop-system variable	Rainfed	Irrigated	Difference ¶
Grain yield (t ha^{-1})	5.9 (CV = 23%)	13.2 (CV = 3%)	+124%
Energy input (GJ ha^{-1})	10.8	30.0	+178%
Net energy yield (grain energy minus fossil-fuel energy)	74	159	+115%
N fertilizer efficiency (kg grain kg^{-1} N)	54	71	+32
Water productivity (kg $ha^{-1}mm^{-1}$)	8.8	14.0	+59
GHG intensity (kg CO_2e t^{-1})‡	388	231	-40%

¶ Relative to rainfed maize values. Based on data from 2005-2007.

† Includes emissions of CO_2, N_2O, and CH_4 adjusted for CO_2 warming equivalent. N_2O estimated by the N-surplus method of Van Groenigen *et al.* (2010).

‡ GHG emissions per metric ton of grain production

Grassini & Cassman, 2012: Proc. Natl Acad. Sci.

Take home from Environmental Assessment of Irrigated Corn in Nebraska

- **Although NE irrigated corn receives large inputs of N fertilizer, water, and energy, compared to rainfed corn it has:**
  - **Greater N fertilizer efficiency**
  - **Greater net energy yield**
  - **Smaller global warming potential intensity**
- **Good news for modern, science-based agriculture**
  - **Goals of high yield, high input efficiency, large energy yield, and minimal GHG emissions are complementary**
  - **Significant potential to further improve environmental performance of high-yield systems**

Conclusions—Getting Ahead of the Curve

- **Conventional agriculture and associated industries are continually behind the curve and on the defensive about environmental concerns and standards**
  - **Agenda and metrics are established by those who know little about agriculture or care about its fate**
  - **"Crisis mode " in response to bad science; negative perceptions are extremely difficult to change**
  - **Increased monitoring of environmental performance is driven by the food industry, environmental NGOs, and public perceptions about impact of agriculture on the environment**
  - **Ironically, high-yield, science-based agriculture is actually quite good and getting better in terms of fertilizer, water, energy efficiency, and has relatively low global warming potential**
- **Tremendous opportunities to set environmental agenda if fertilizer, seed, and agricultural equipment companies provide leadership to support research and extension**