Food Security in a World of Natural Resource Scarcity:

The Role of Agricultural Technologies

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Project Overview

Business as Usual: Challenges and Threats = Continued Scarcity

- **Challenges**
  - Climate change
  - Water scarcity
  - Biofuel demand
  - Income
  - Population growth

Higher food prices

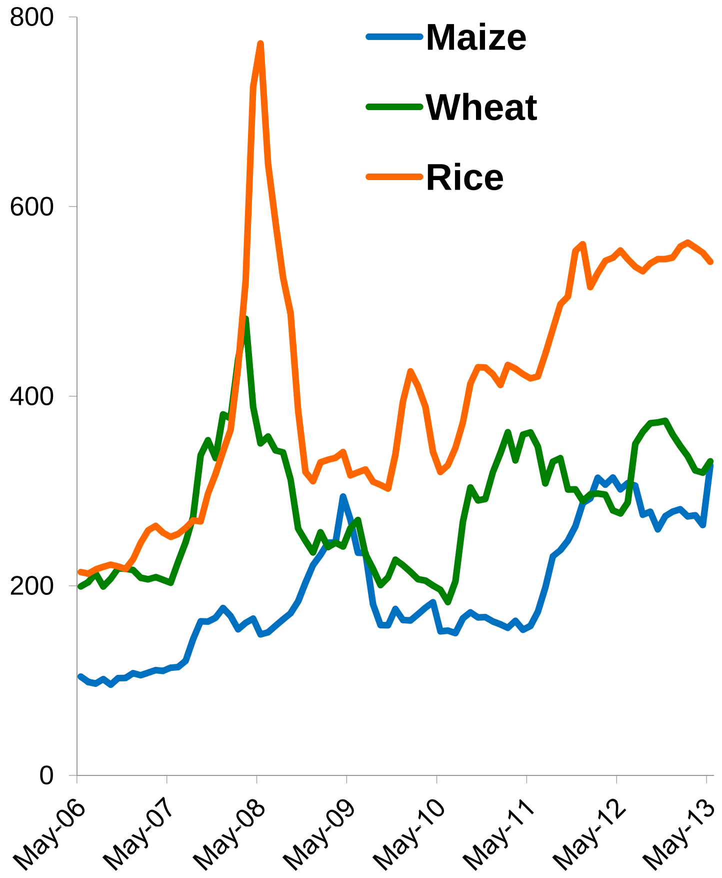
- **Growing threats to**:
  - Land
  - Environmental preservation
  - Water
  - Biodiversity

- **Enhanced investment in agricultural research + technological change** → Game-changer for productivity and food security

- **Lack sufficient knowledge on**
  - Disaggregated impacts of specific technologies by country
  - Agroclimatic zone

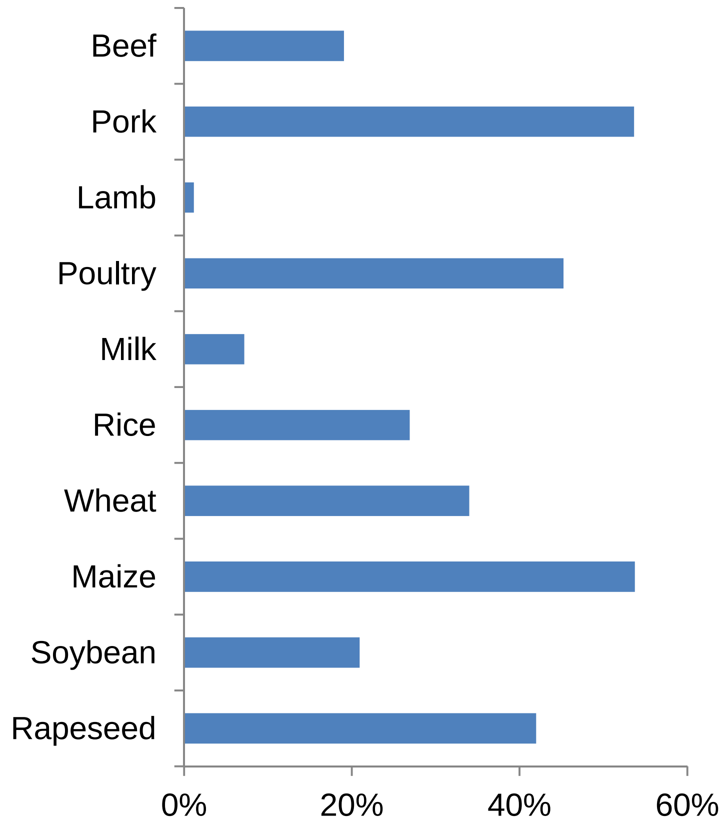
High and Volatile Food Prices

Global cereal prices (US$/ton)



Source: Data from FAO 2013

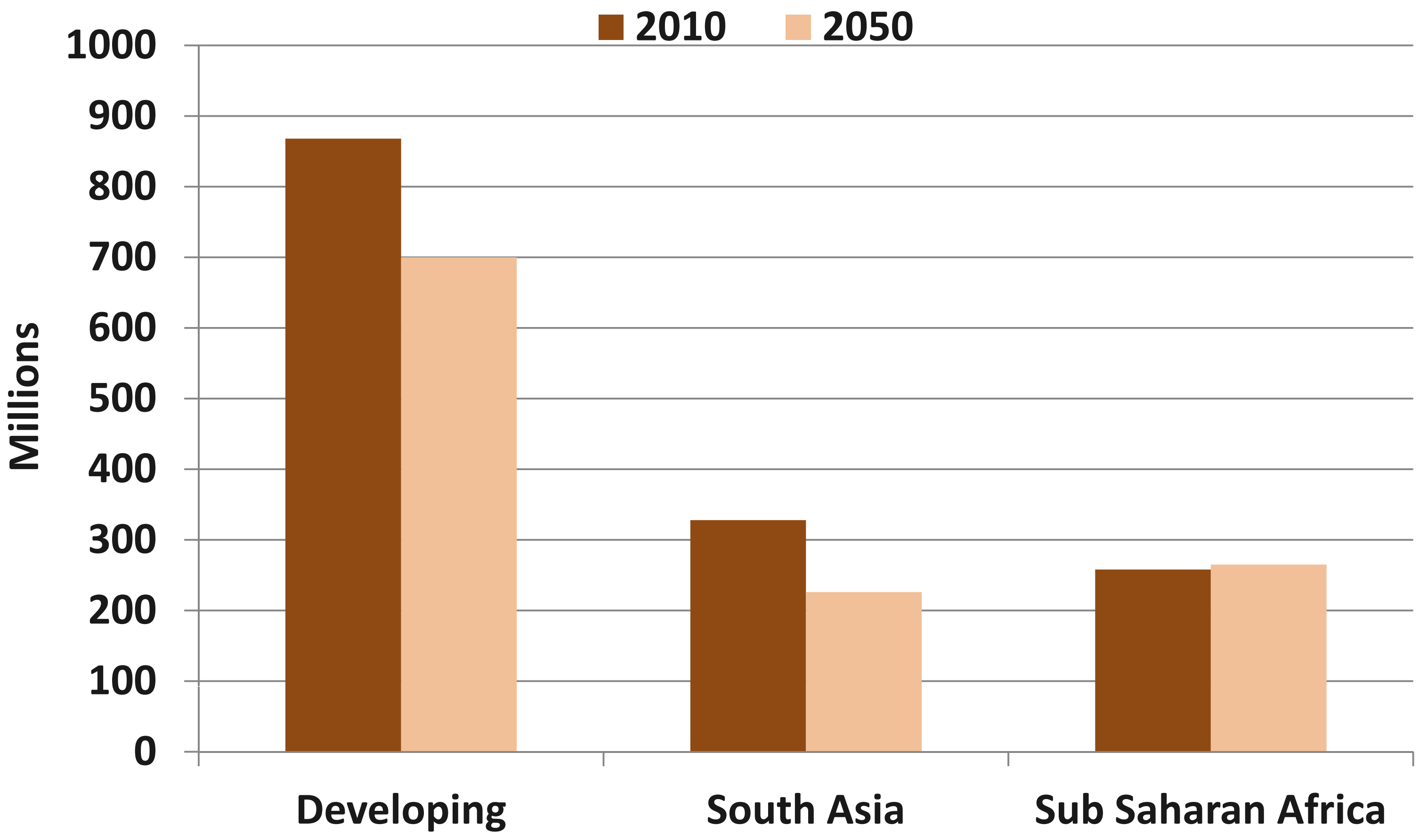
Projected changes in global agricultural commodity prices, 2010-2050 (%)



Source: Rosegrant et al. 2013

Notes: The changes are for business as usual scenario

Population at Risk of Hunger, 2010 and Projected 2050



Source: Rosegrant et al. 2012

Technology Assessment Scope

- **Global & Regional**
- **Eleven technologies**
  - No-Tillage
  - Integrated Soil Fertility Management
  - Organic Agriculture
  - Precision Agriculture
  - Crop Protection
  - Drip Irrigation
  - Sprinkler Irrigation
  - Water Harvesting
  - Drought Tolerance
  - Heat Tolerance
  - Nitrogen Use Efficiency
- **Three Crops**
  - **Wheat**
  - **Rice**
  - **Maize**

Agricultural Technologies

- **No-till**: Minimal or no soil disturbance, often in combination with retention of residues, crop rotation, and use of cover crop
- **Integrated soil fertility management**: A combination of chemical fertilizers, crop residues, and manure/compost
- **Precision agriculture**: GPS-assisted delivery of agricultural inputs and low-tech management practices aim to control all field parameters (input delivery, plant spacing, water level)
- **Organic agriculture**: Cultivation with exclusion of or strict limits on use of manufactured fertilizers, pesticides, growth regulators, and genetically modified organisms
- **Water harvesting**: Water channeled toward crop fields from macro- or micro-catchment systems, or use of earth dams, ridges, or graded contours
- **Drip irrigation**: Water applied as a small discharge directly around each plant or to the root zone, often using microtubing

Agricultural Technologies

- **Sprinkler irrigation**: Water distributed under pressure through pipe network and delivered to the crop via overhead sprinkler nozzles
- **Heat tolerance**: Improved varieties showing characteristics that allow the plant to maintain yields at higher temperatures
- **Drought tolerance**: Improved varieties showing characteristics that allow the plant to have better yields compared with regular varieties due to enhanced soil moisture uptake capabilities and reduced vulnerability to water deficiency
- **Nitrogen-use efficiency**: Plants that respond better to fertilizers
- **Crop protection**: The practice of managing pests, plant diseases, weeds and other pest organisms that damage agricultural crops

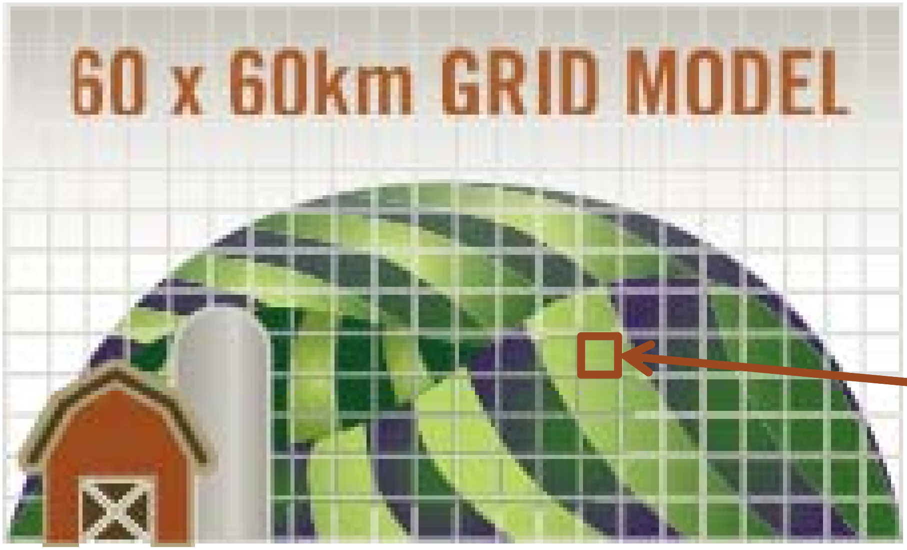
Modeling Tools

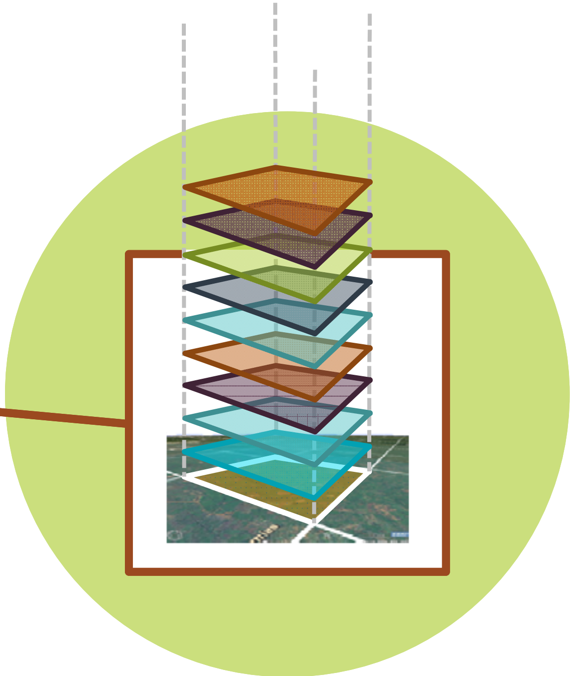
- **DSSAT**
  - Biophysical model - assesses impact of single technology or technology mix
    - Productivity (yields)
    - Resource use (water, N losses)
- **IMPACT**
  - Global economic agricultural model - assesses changes in productivity due to technology adoption
    - Food production, consumption, trade
    - International food prices
    - Calorie availability, food security

DSSAT Crop Models

- Simulate plant growth and crop yield by variety day-by-day, in response to
  - Temperature
  - Precipitation
  - Soil characteristics
  - Applied nitrogen
  - CO_2 fertilization
  - Other management factors
- DSSAT-based simulations at crop-specific locations (using local climate, soil and topographical attributes)

High Resolution of Analysis





Resolution of Grid:

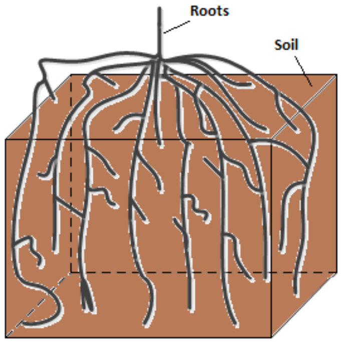
- 30 arc-minute, or 0.5 degree (60 km by 60 km)
- 95,280 cells globally
- **21,385 cells** covering crop land extent for three crops simulated in this study

Management Scenarios

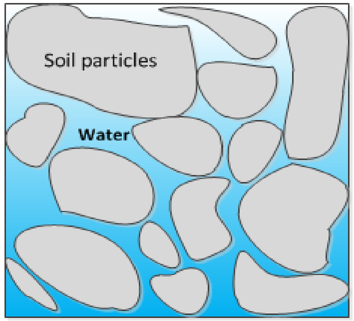
- **Business-as-usual scenario**
  - Country/crop/input system-specific inorganic fertilizer application rate
  - Furrow irrigation, where irrigation is adopted
  - Sub-optimal planting density & sub-optimal planting window
  - Conventional tillage, where no-till is not yet adopted
  - Representative, optimal varieties based on agro-ecological conditions
  - Current, actual yield loss due to biotic constraints
- **Technology scenarios**
  - Specific representation of each technology
  - Area of adoption in 2050 depends on positive yield impact of technology
- **Climate change scenarios 2050s**
  - MIROC A1B (used in this presentation)
  - CSIRO A1B

Sample Technology Specification:
Drought Tolerance

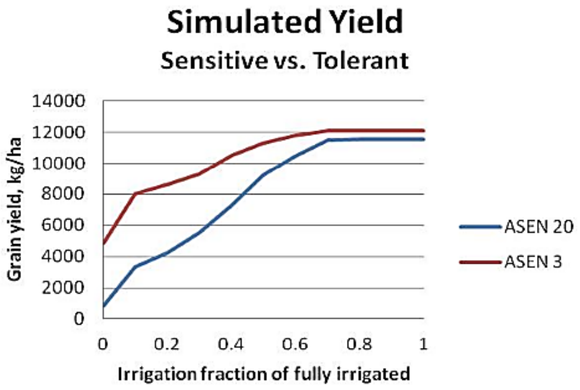
- Increased root volume
  - Implemented by increasing root growth factor parameters



- Enhanced root water extraction capability
  - Implemented by decreasing lower limit of available soil moisture parameters

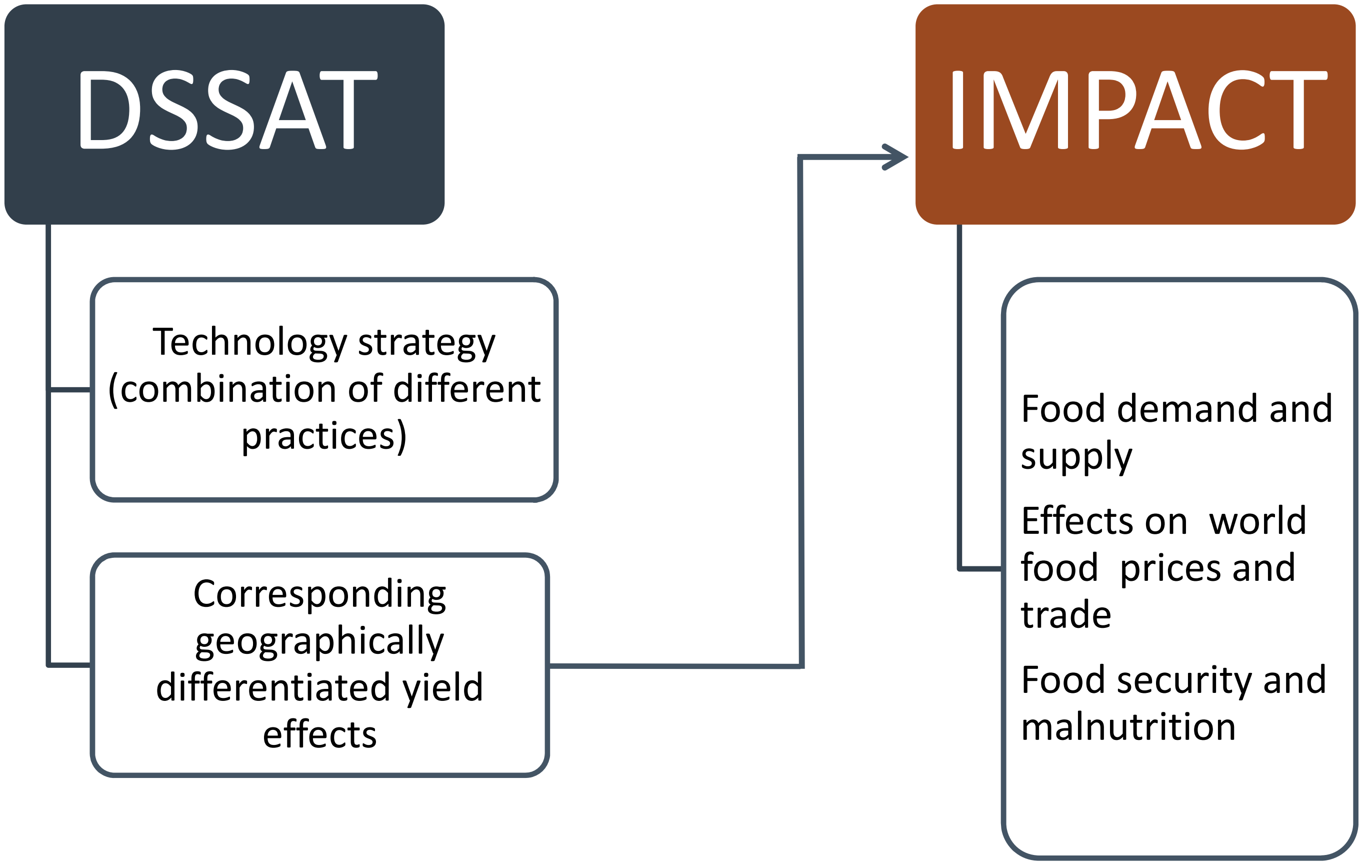


- For maize, less sensitive to ASI (anthesis to silking interval)
  - Implemented by modifying the existing model to have differential ASI as a cultivar trait, driven by shoot growth rate*



* In collaboration with Ag. Bio. Engineering Dept., University of Florida

Crop model (DSSAT) linked with Global Partial Equilibrium Agriculture Sector Model (IMPACT)



IMPACT Model

- Disaggregated agricultural commodities (56 commodities)
- Disaggregated spatial allocation of crop production at sub-national level (159 countries, and 320 food production units)
- Details on physical use of land and water, trade policies, with resulting trade
- World food prices are determined annually at levels that clear international commodity markets
- Iterative year-by-year demand and supply equilibration
- Output indicators – area, yield, and production of crops and livestock, food demand, food prices, calorie availability, international trade, malnutrition measures, share of population at risk of hunger, water consumption

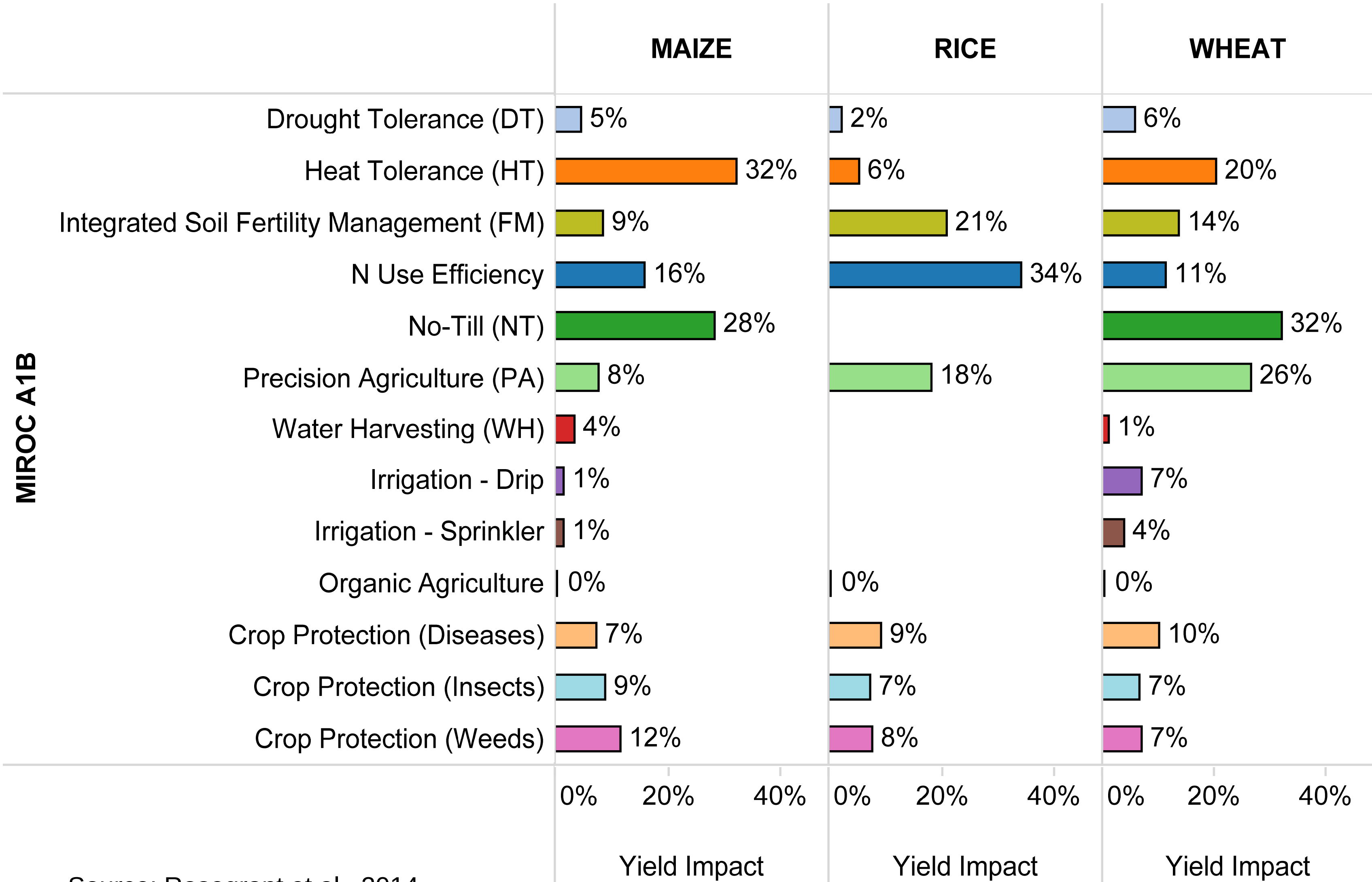
IMPACT Model

- Crop area is a function of crop prices, irrigation investment, water input, climate change
- Yield is a function of crop price, input prices, irrigation investment, water inputs, exogenous yield growth, climate change, technology adoption
- Food demand is a function of commodity prices, income, and population
- Feed demand is a function of livestock production, feed prices, and feeding efficiency
- Biofuel demand is computed based on policy mandates and targets

DSSAT Results

Global DSSAT Results

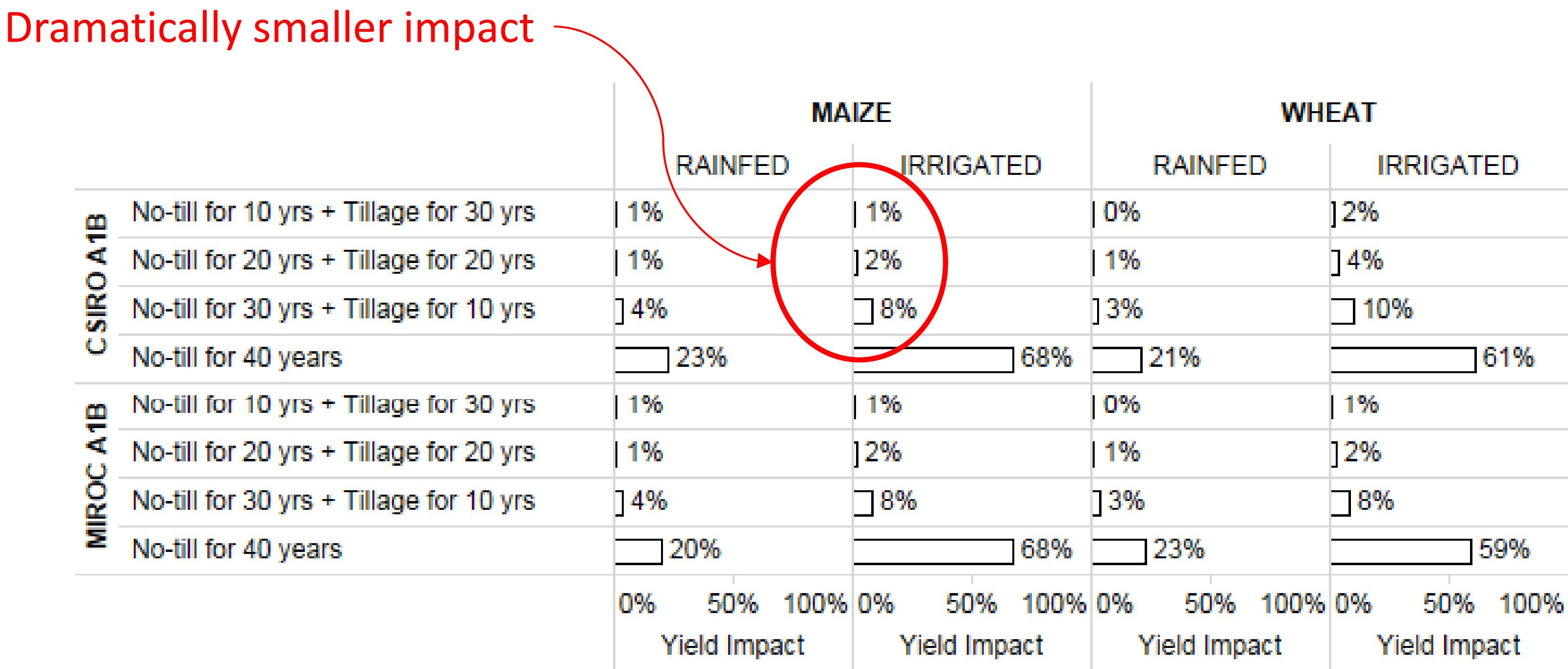
Yield Change (%) – Maize, Rice, & Wheat, 2050 vs. Baseline



Source: Rosegrant et al. 2014.

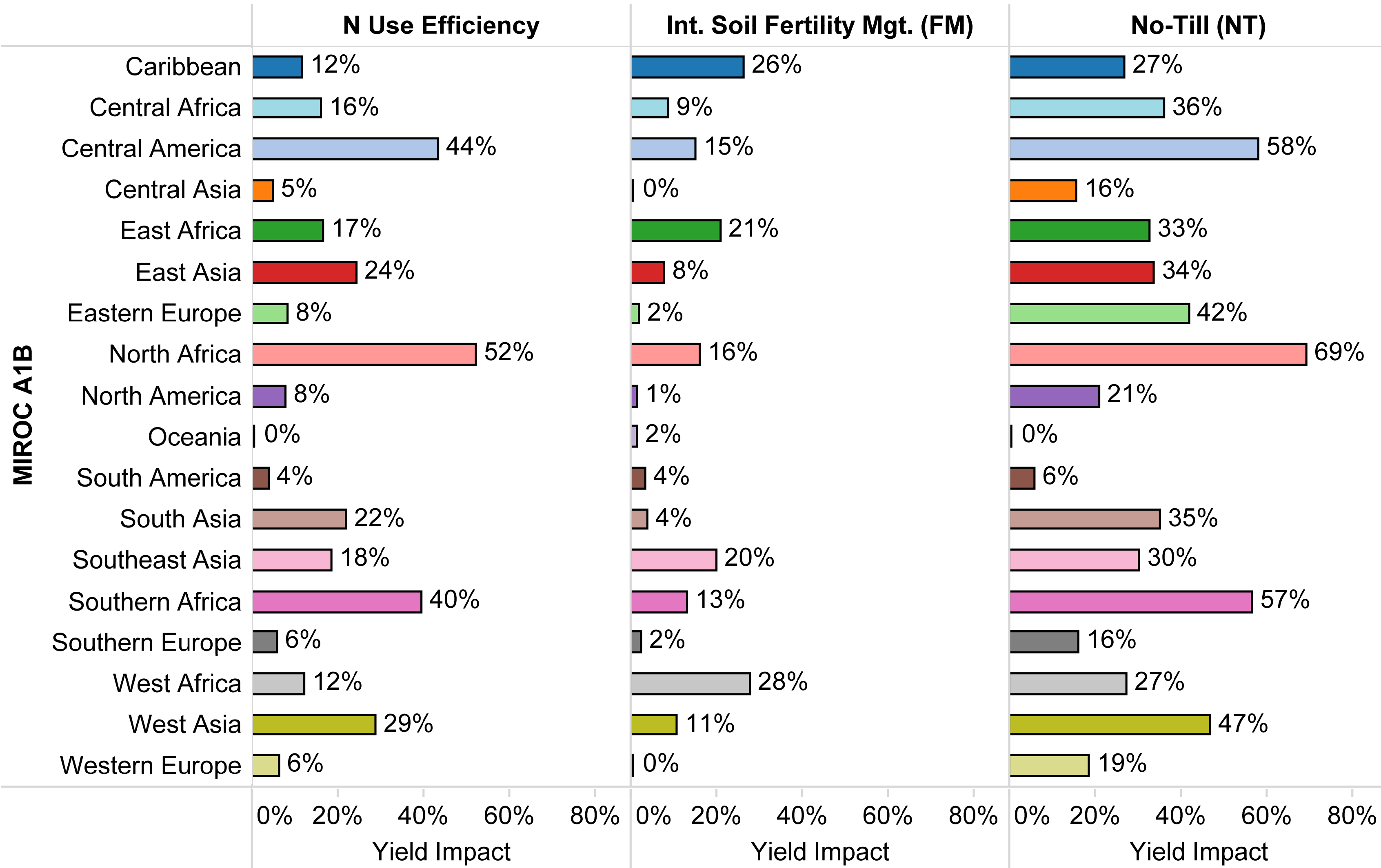
NO-TILL: Long term management is essential

- We assume farmers continue practicing no-till for 40 years; yield impact is calculated for the end period (years from 31 to 40)
- What if farmers stop practicing no-till?



Regional DSSAT Results, Maize:

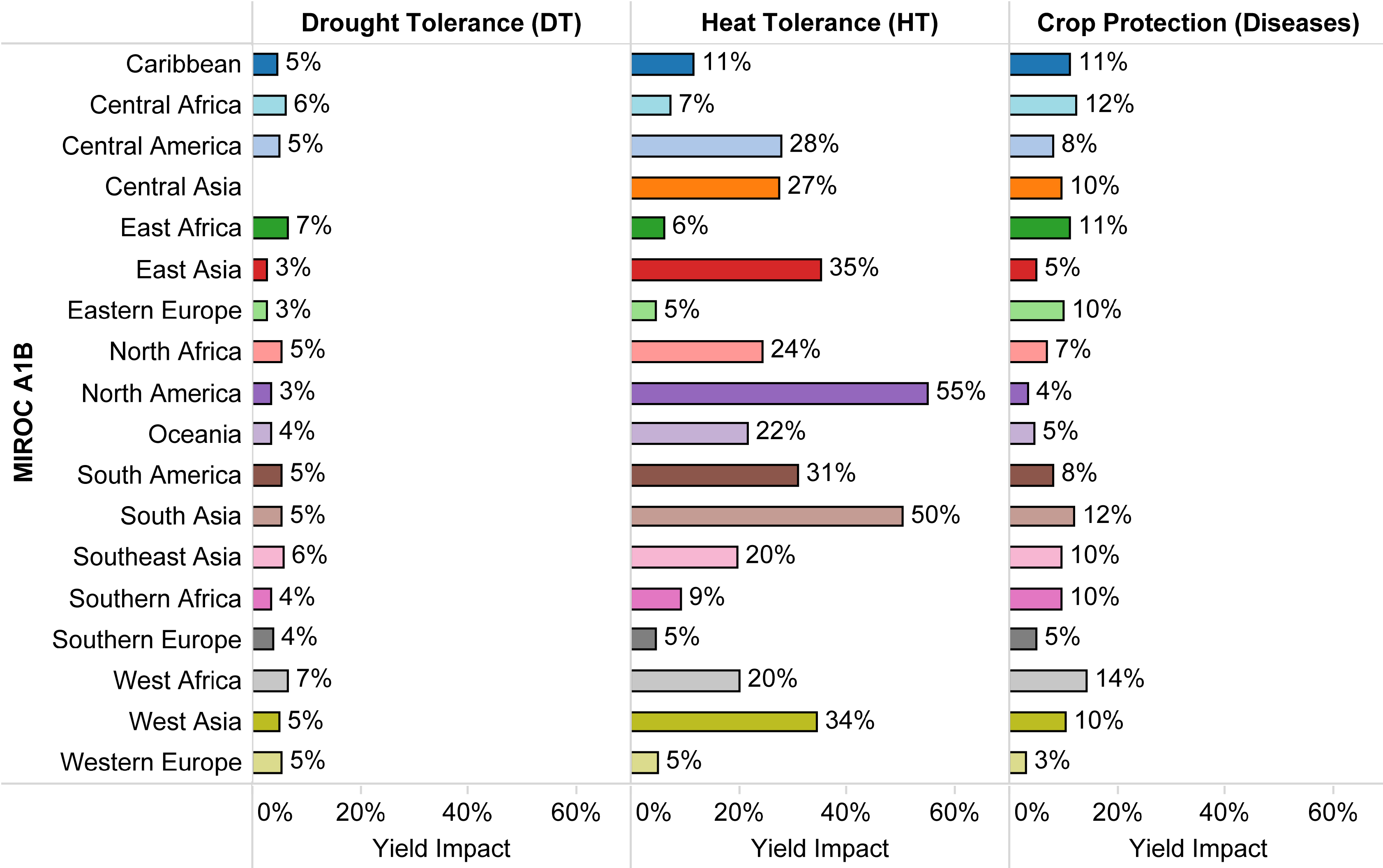
NUE, ISFM, and No-till, 2050 vs. Baseline



Source: Rosegrant et al. 2014.

Regional DSSAT results, Maize:

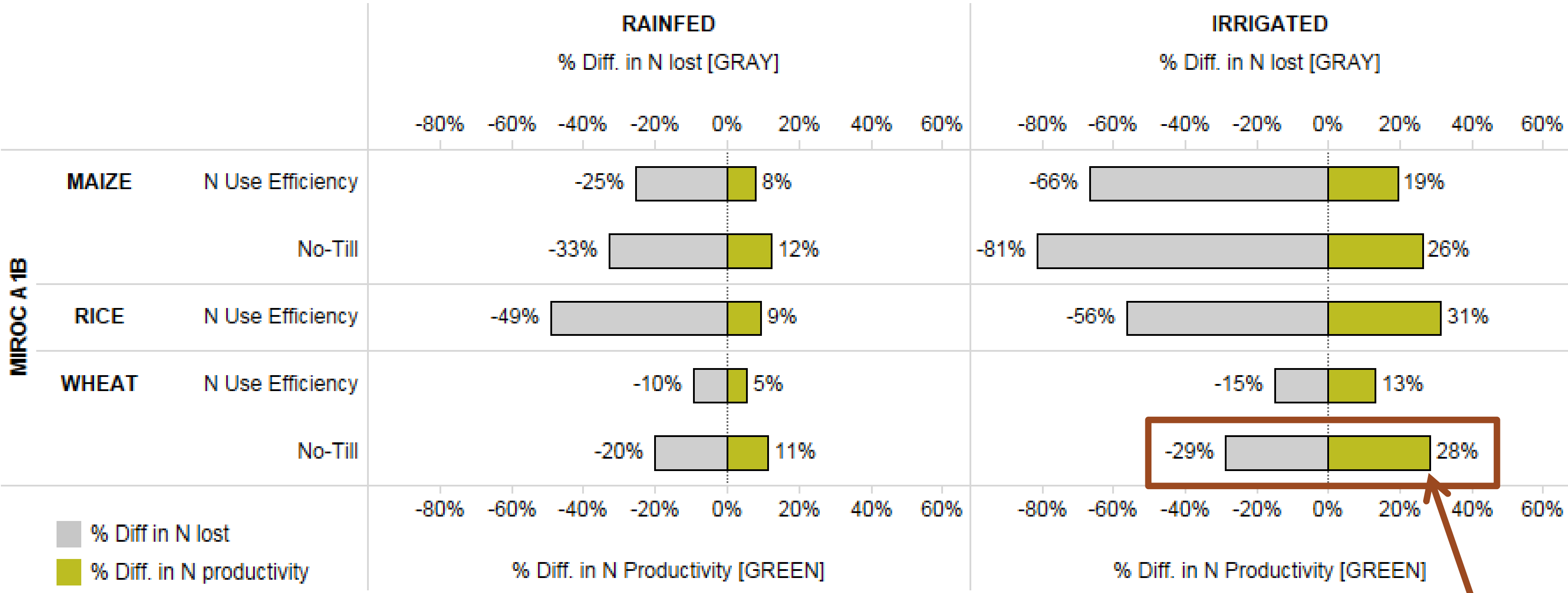
Drought Tolerance, Heat Tolerance and Crop Protection (disease), 2050, compared to baseline



Source: Rosegrant et al. 2014

Efficient Use of Resources:

Change (%) in N Productivity – **Maize, Rice, Wheat**. Irrigated vs. Rainfed, 2050 vs. Baseline (DSSAT)



(Compared to the business-as-usual)

29% less nitrogen losses

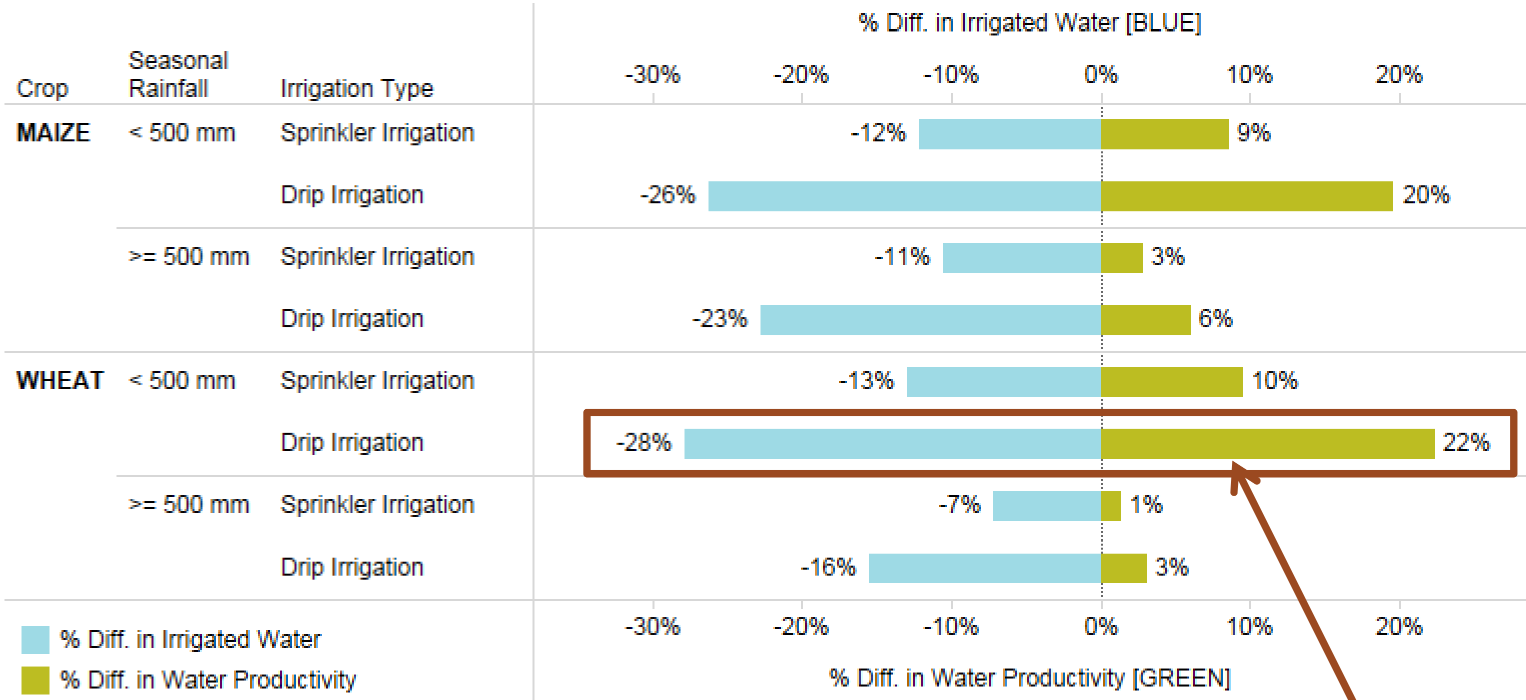
→ 28% more N productivity

Benefits include reduced N losses, increased N productivity, reduced GHG emissions.

Source: Rosegrant et al. 2014.

Efficient Use of Resources :

Change in Site-specific Water Use – Irrigated **Maize, Wheat**



(Compared to the conventional furrow irrigation)

28% less water applied

→ 22% more water productivity

Prominent impacts of

Improved Irrigation Technologies

- Increased water savings (less water used)
- Increased water productivity (more biomass produced per unit water input)

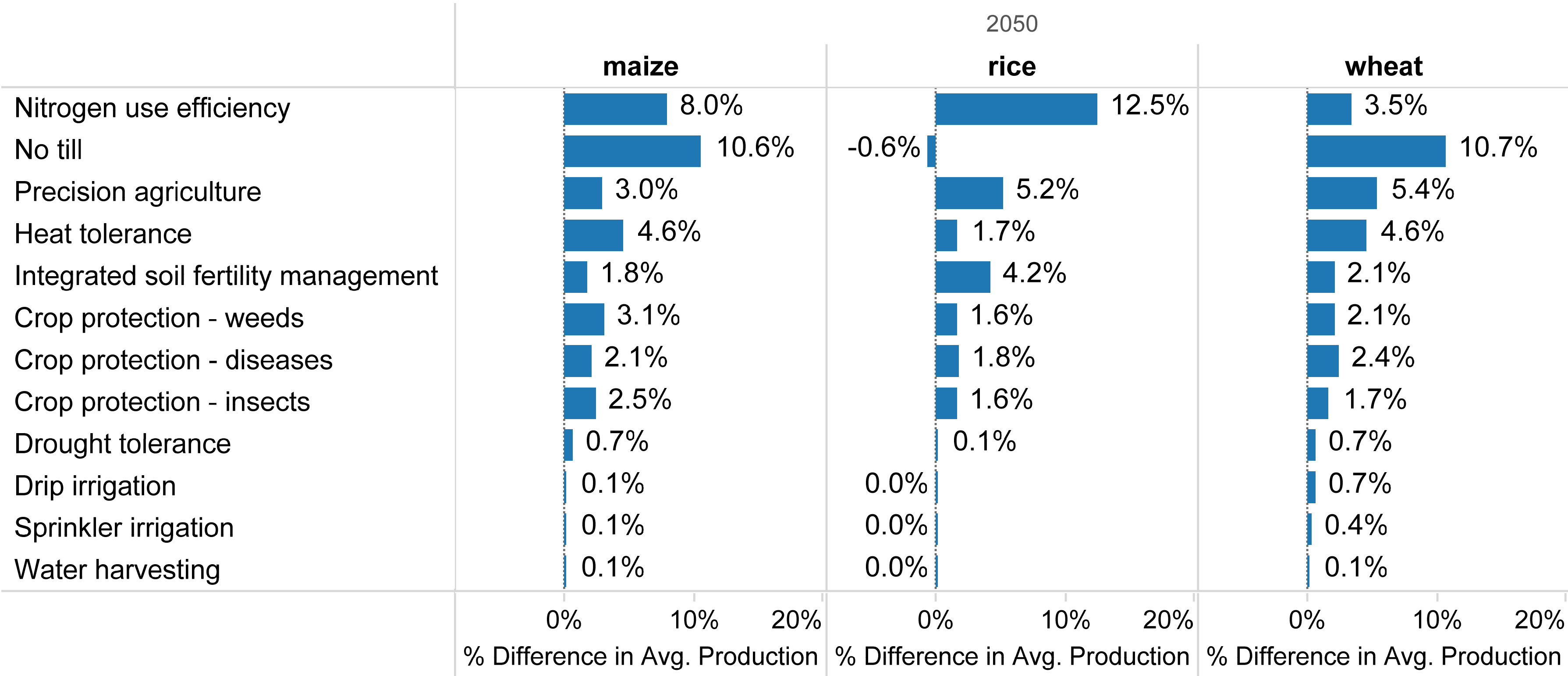
Source: Rosegrant et al. 2014.

IMPACT Results

Adoption Pathway Ceilings (%)

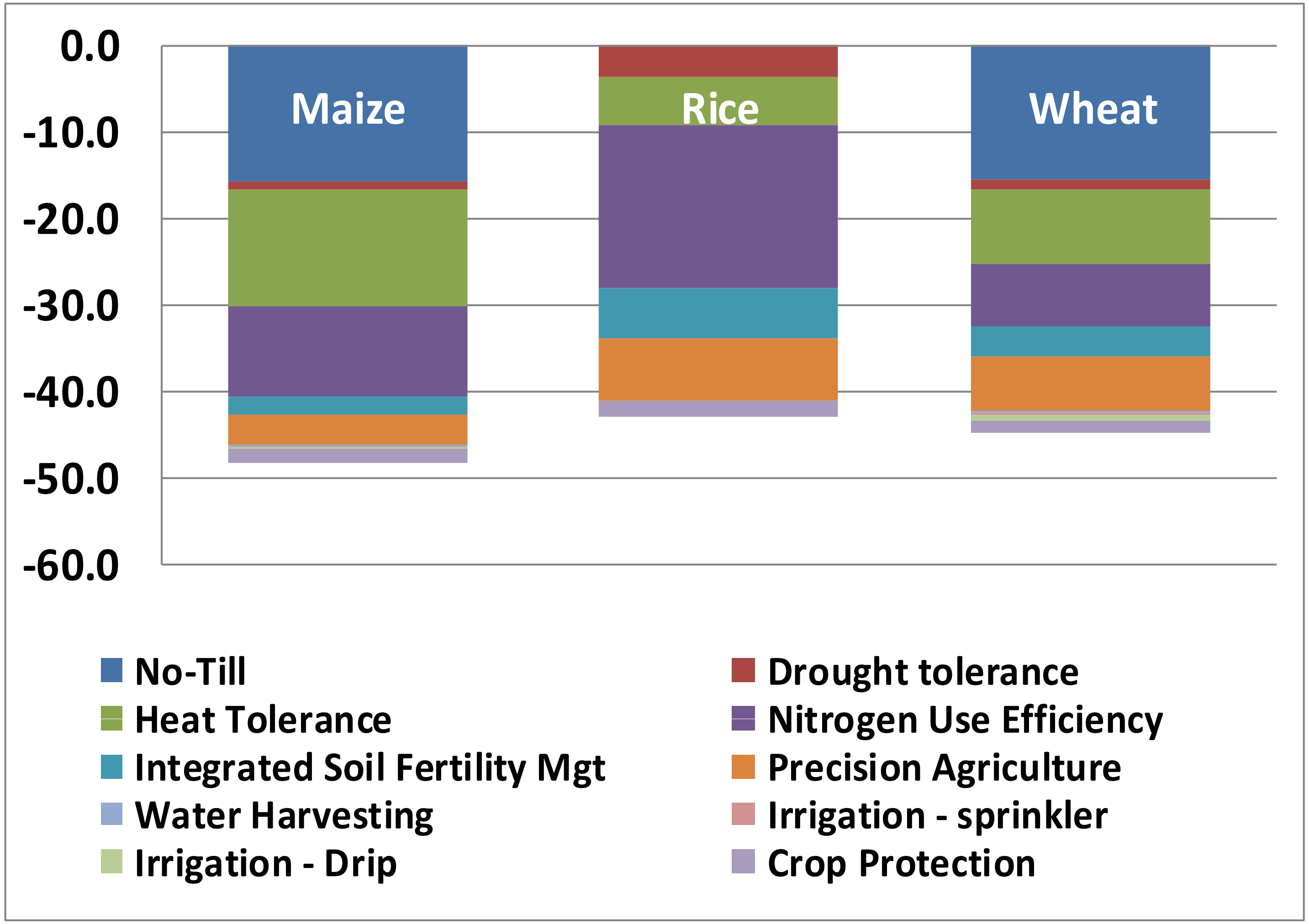
Technology	Ceiling
Drought tolerance	80
Heat tolerance	75
Nitrogen-use efficiency	75
No-till	70
Integrated soil fertility management	40
Water harvesting	40
Drip irrigation	40
Sprinkler irrigation	40
Precision agriculture	60
Crop protection-diseases	50
Crop protection-weeds	50
Crop protection-insects	50

Percent Change in Total Production, Developing Countries: Maize, Rice, Wheat, 2050 with Technology vs. 2050 Baseline (IMPACT)



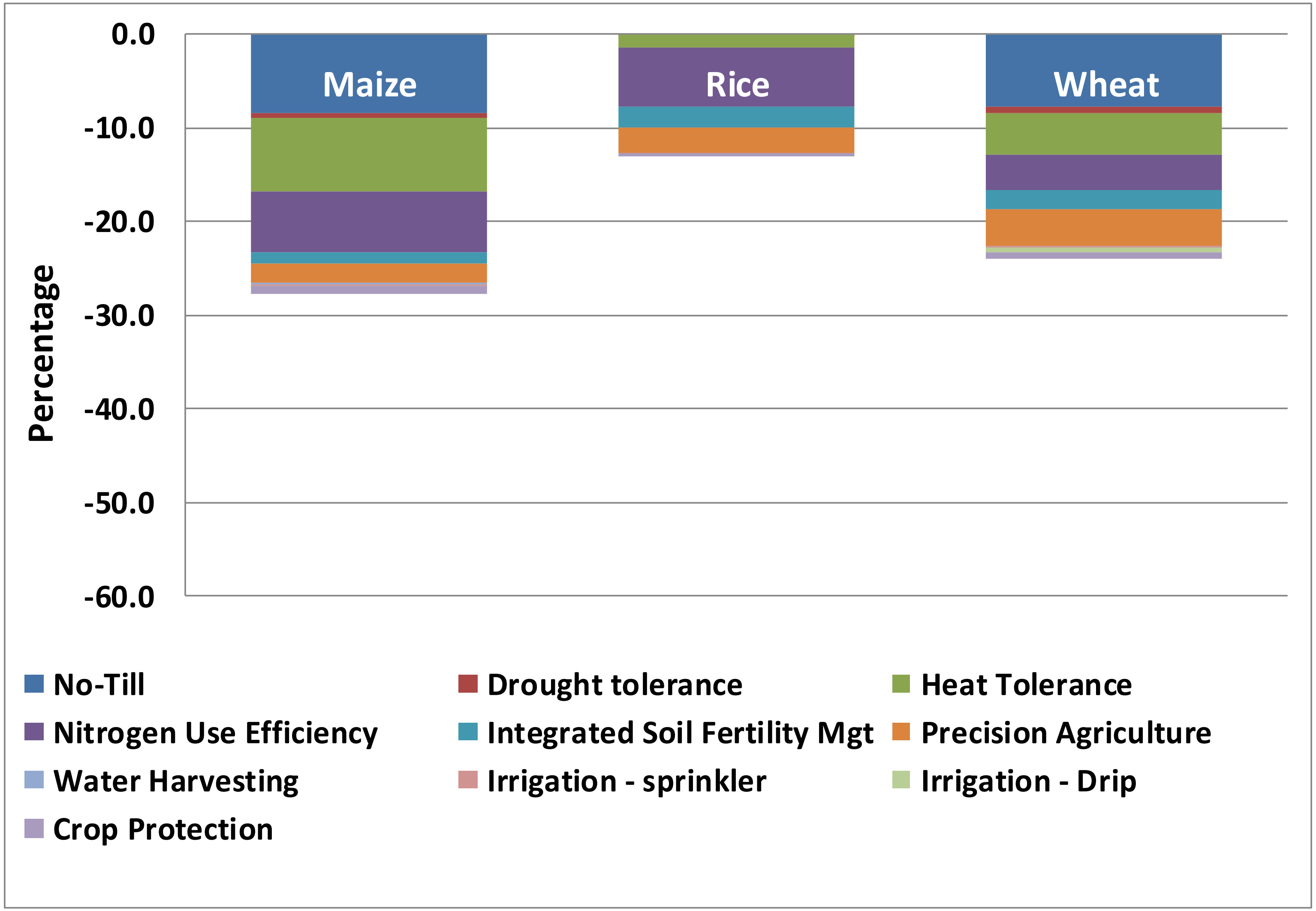
Source: Rosegrant et al. 2014.

Price Effects of Technologies, 2050, compared to Baseline: Global – Combined Technologies



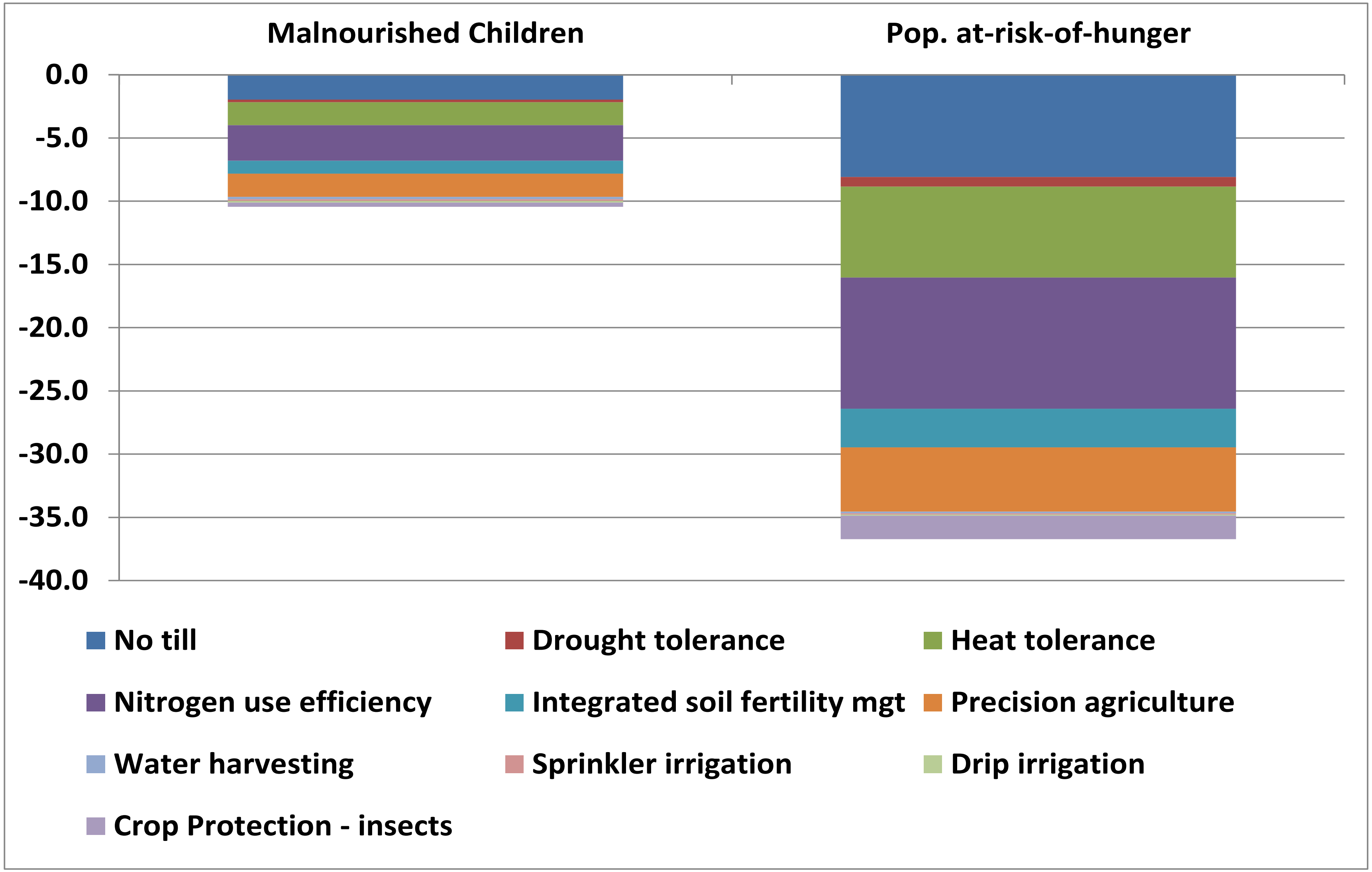
Source: Rosegrant et al. 2014.

Percent Change in Harvested Area, 2050, Compared to Baseline: Global – Combined Technologies



Source: Rosegrant et al. 2014.

Food Security Effects of Technology relative to 2050 Baseline



Source: Rosegrant et al. 2014

Key Messages

Key Messages

- Adoption of this set of technologies significantly reduces projected food prices in 2050 compared to climate change baseline
- Farmer adopters will increase real income because technological change is faster than price decline
- Number of people at risk of hunger could be reduced by 36% in 2050 compared to baseline with adoption of combined technologies under feasible adoption pathways

Key Messages

- Improved land management (No-till, precision agriculture, integrated soil fertility management)
  - Large yield impacts in many regions
- Nitrogen use efficiency in new varieties
  - Strong yield impacts
  - Reduces negative environmental impacts from fertilization
- Heat tolerant varieties
  - Reduce projected negative impacts of climate change
- Drought tolerant varieties
  - Perform as well as susceptible varieties under no drought stress
  - Significant yield benefits under drought conditions

Key Messages

- **Crop protection** has strong positive yield impacts
- Technology impacts are higher with **irrigation**
- Large regional differences in agricultural technology impacts
- Important to target specific investments to specific regions
  - Heat tolerance to North America and South Asia
  - Drought tolerance to LAC, MENA, SSA
  - Crop protection to SSA, SA, and Eastern Europe

Key Messages

- Organic agriculture is not a preferred strategy for the 3 crops; has a role in niche high-value markets
- Given growing natural resource scarcity, technologies that reduce resource use are important:
  - No-till
  - Integrated soil fertility management
  - Nitrogen use efficiency
  - Precision agriculture
  - Drip and sprinkler irrigation

Conclusions and Policy Implications

Building Sustainable Productivity Growth and Resilient Agricultural and Food Systems

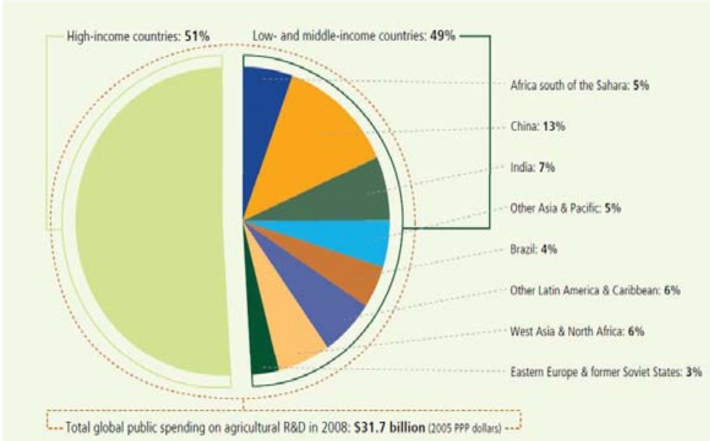
1. Accelerate investments in agricultural R&D for productivity growth
2. Promote complementary policies and investments
3. Reform economic policies

1. Accelerate Investments in Agricultural R&D for smallholder productivity

Invest in technologies for

- Crop and livestock breeding
  - High-yielding varieties
  - Biotic- and abiotic-stress resistant varieties
- Modernize breeding programs in developing countries through provision of genomics, high throughput gene-sequencing, bio-informatics and computer tools
- GMOs where genetic variation does not exist in the crop
  - Nitrogen use efficiency
  - Drought, heat and salinity tolerance
  - Insect and disease resistance

Global public spending on agric. R&D, 2008 (%)



Source: ASTI 2012

2. Promote Complementary Policies and Investments

- Invest in rural infrastructure and irrigation
- Increase access to high-value supply chains and markets e.g. fruits, vegetables, and milk
- Regulatory reform: Reduce hurdles to approval and release of new cultivars and technologies
  - Remove impediments (e.g. restrictive "notified" crop lists, excessive testing and certification requirements, foreign investment barriers, ad hoc biosafety decision-making)
- Extension of farming systems: minimum tillage, integrated soil fertility management, integrated pest management, precision agriculture

3. Reform Economic Policies

- Support open trading regimes to share climate risk
- Use market-based approaches to manage water and environmental services combined with secure property rights
- Reduce subsidies that distort production decisions and encourage water use beyond economically appropriate levels
  - Fertilizer, energy, water subsidies
  - Savings invested in activities that boost farm output and income

Online Tool with Downloadable Data

http://apps.harvestchoice.org/agritech-toolbox/

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