Nutrient Use Efficiency – Measurement and Management in a Time of New Challenges

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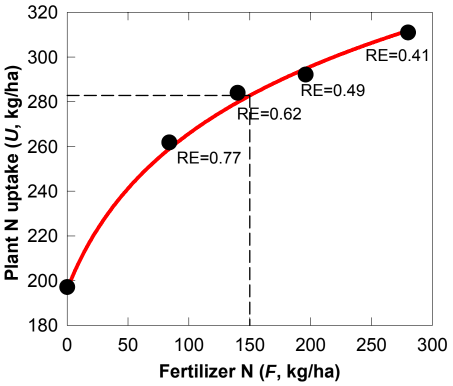
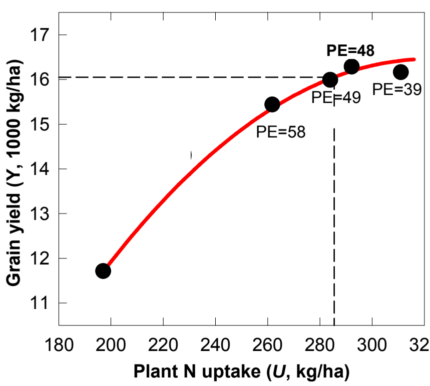
- Definition of nutrient use efficiency
- Some general rules of thumb: N, P & K
- New challenges for FBMP

<u>Emphasis on cereals:</u>

~2/3% of global fertilizer use

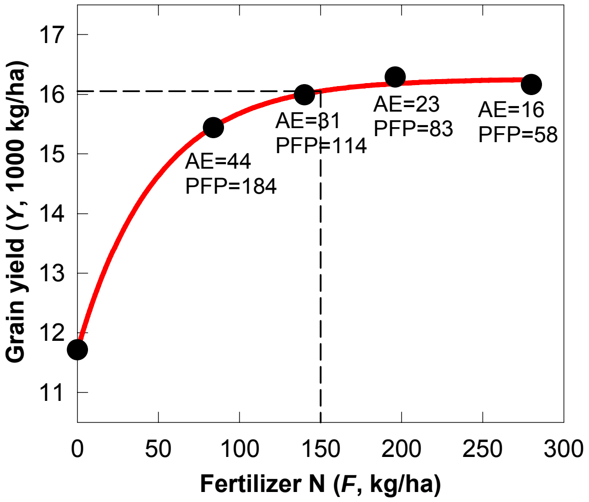
~20% of global creation of reactive N (Nr)





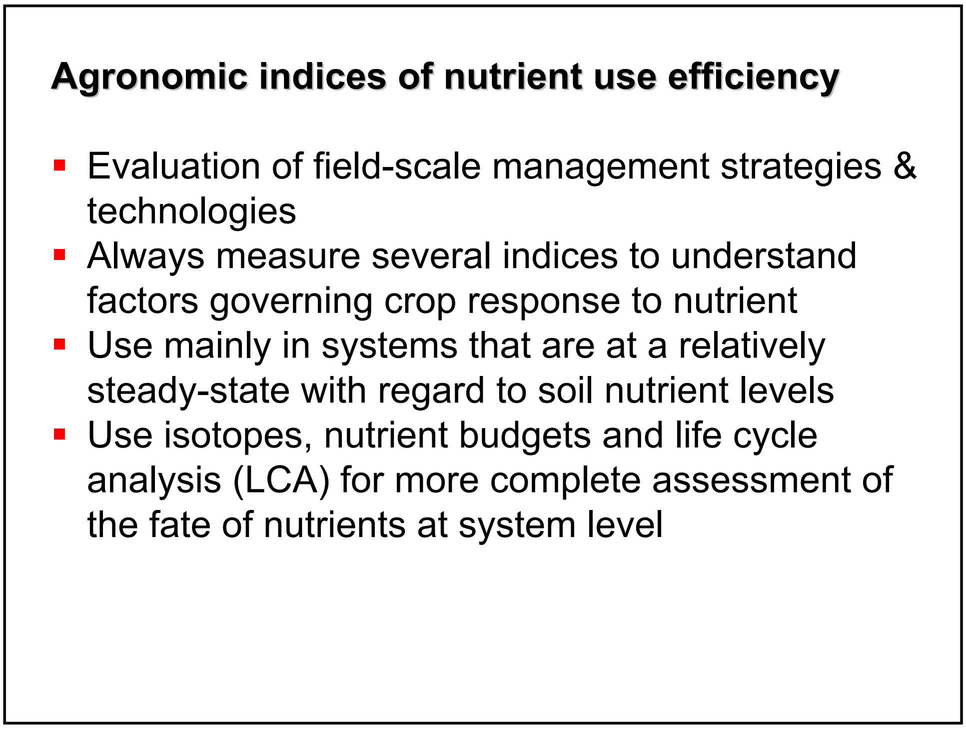
Recovery efficiency (‘apparent’)
= kg increase in crop uptake per kg nutrient applied
RE = $(U - U_0)/F$
→ Crop sink size
→ Fertilizer management

Physiological efficiency
= kg yield increase per kg increase in crop uptake
PE = $(Y - Y_0)/(U - U_0)$
→ Climate, genotype & crop management



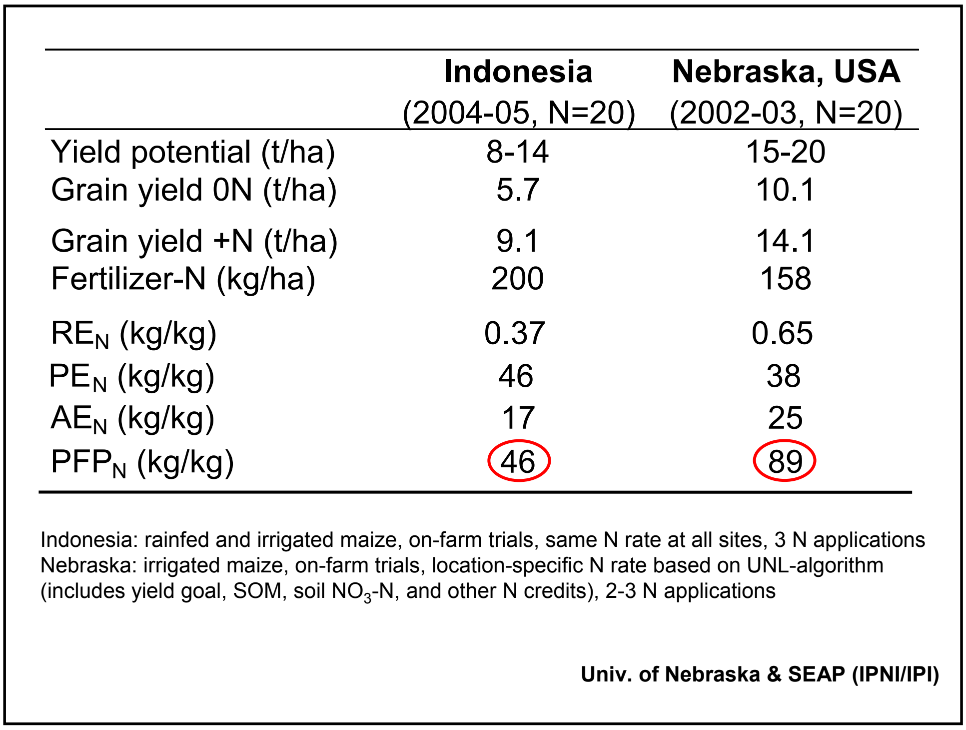
Agronomic efficiency
= kg grain yield increase per kg applied
AE = $(Y - Y_0)/F$
AE = PE x RE

Partial factor productivity
= kg grain yield per kg N applied:
PFP = $Y/F = (Y_0/F) + AE$
→ Indigenous supply and AE



Agronomic indices of nutrient use efficiency

- Evaluation of field-scale management strategies & technologies
- Always measure several indices to understand factors governing crop response to nutrient
- Use mainly in systems that are at a relatively steady-state with regard to soil nutrient levels
- Use isotopes, nutrient budgets and life cycle analysis (LCA) for more complete assessment of the fate of nutrients at system level

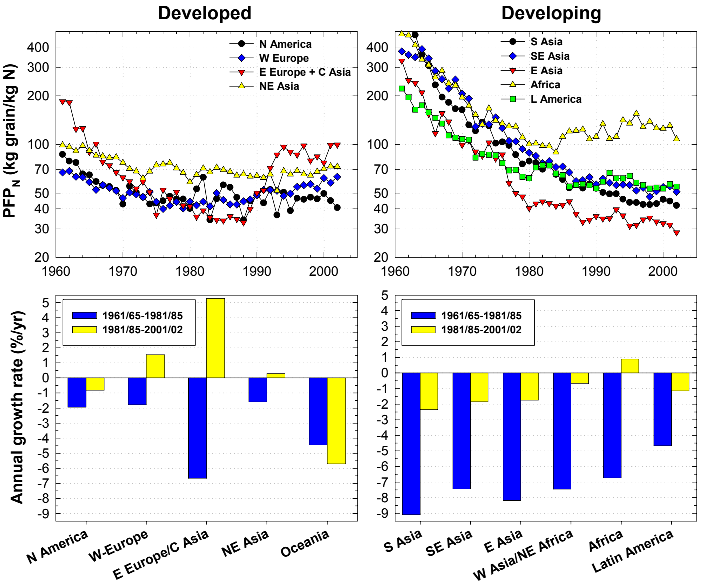


	Indonesia	**Nebraska, USA**
	(2004-05, N=20)	(2002-03, N=20)
Yield potential (t/ha)	8-14	15-20
Grain yield 0N (t/ha)	5.7	10.1
Grain yield +N (t/ha)	9.1	14.1
Fertilizer-N (kg/ha)	200	158
RE_N (kg/kg)	0.37	0.65
PE_N (kg/kg)	46	38
AE_N (kg/kg)	17	25
PFP_N (kg/kg)	46	89

Indonesia: rainfed and irrigated maize, on-farm trials, same N rate at all sites, 3 N applications
Nebraska: irrigated maize, on-farm trials, location-specific N rate based on UNL-algorithm (includes yield goal, SOM, soil NO_3-N, and other N credits), 2-3 N applications

Univ. of Nebraska & SEAP (IPNI/IPI)

Nitrogen



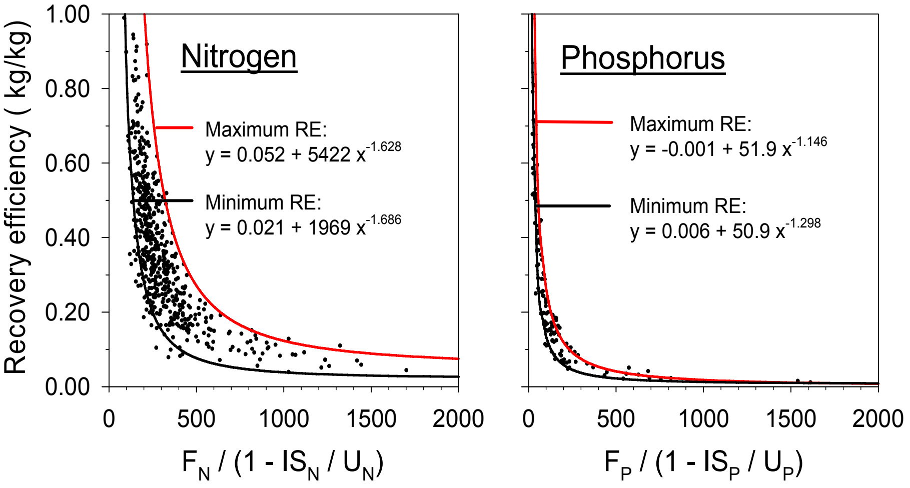
FAOSTAT (FAO, 2004) & Fertilizer use by crops (IFA et al., 2002)

Crop	Region (observations)	N rate kg/ha	PFP$_N$ kg/kg	AE$_N$ kg/kg	RE$_N$ %
Maize, reseach trials (1)	World (21-50)	123	72	24	65
Maize, on-farm (2)	USA (52)	158	61	12	36
Maize, on-farm (3)	Indonesia (20)	200	46	17	37
Rice, research trials (1)	World (295-307)	115	62	22	46
Rice, on-farm (4)	Asia (179)	117	49	12	31
Rice, on-farm (5)	West Africa (151)	106	46	17	36
Wheat, research trials (1)	World (286-507)	112	45	18	57
Wheat, on-farm (6)	India (46)	134	44	11	34

1 Ladha et al. (2005), Adv. Agronomy, difference method
2 D. Walters, UNL, 1995-1998, 52 farm sites in IL, KS, MI, MN, MO, NE, WI, difference method
3 A. Dobermann, 2004-2005, 20 farms, difference method
4 Dobermann et al. (2002), farmers' practice, 179 farms in six countries, difference method
5 Wopereis et al. (1999) and Haefele et al. (2001), farmers' practice, difference method
6 A. Dobermann, 1998-1999, 23 farms in Uthar Pradesh, difference method

Research trials + top farmers	50-70	20-30	50-70
Farmers' fields	40-50	10-20	30-50

+ 5-6% additional N recovery in subsequent crops



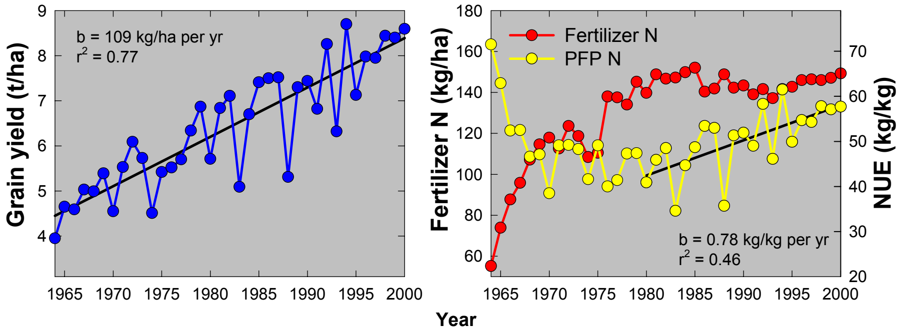
Influence of fertilizer rate (F, kg/ha), effective nutrient supply from indigenous sources (IS, kg/ha), and crop nutrient uptake (U, kg/ha) on the range of recovery efficiencies of N and P from applied fertilizer in irrigated rice. Values shown are based on on-farm studies conducted at 179 field sites in Asia during 1997-1998

C. Witt and A. Dobermann, unpublished

Nitrogen

- N supply from indigenous sources and fertilizer efficiency are equally important
- Target AE_N: 20-35 kg grain/kg N applied. Typically, this requires an RE_N of 0.5-0.7 kg/kg
- Optimize the crop N sink and the availability of soil and fertilizer-N for plant uptake at critical stages
- Diagnostic tools for anticipatory (before planting) and responsive (in-season) decisions
- Embedded knowledge (EEF) vs. “knowledge-intensive” approaches: robust and doable
- Farm level support for improved technologies, including local policies that support adoption

N use efficiency in maize, USA



- Greater stress tolerance of modern maize hybrids, transgenics (since 1995)
- Improved management of factors other than N (tillage, seed quality, higher plant densities, weed and pest control, balanced fertilization, irrigation)
- Improved N fertilizer management (research & extension, local policies & incentives to use better management techniques)

Sources: NASS, USDA-ERS cropping practices surveys

Average recovery efficiencies (kg/kg) of N, P and K from mineral fertilizers in field trials with rice, wheat and maize in Asia.

Data set	RE_N	RE_P	RE_K
Rice in S, E and SE Asia, farmers’ practice	0.33	0.24	0.38
Rice in S, E and SE Asia, SSNM	0.43	0.25	0.44
Wheat in India	0.58	0.27	0.51
Wheat in China	0.45	0.22	0.47
Maize in China	0.50	0.24	0.44

Rice: 179 farmers’ fields in five countries, 1997-1998, N=314, (Witt and Dobermann, 2004)
Wheat in India: field trials at 22 sites, 1970-1998. 120-26-50 kg/ha NPK (Pathak et al., 2003)
Wheat and maize in China: field trials across China, 1985-1995 (Liu et al., 2006)

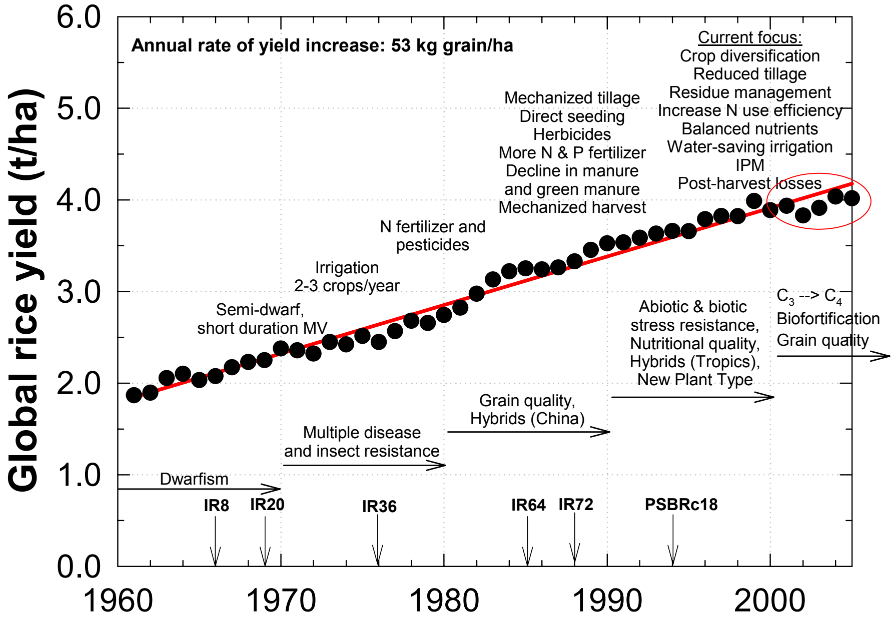
Phosphorus

- Great diversity in P budgets
- Target AE_P: 30-50 kg grain/kg P applied. Typically, this requires an RE_P of 0.15-0.30 kg/kg
- Eliminate other factors that cause low P use efficiency
- Moderate soil P: balance inputs and outputs at field and farm scales to maximize profit and minimize risk of P losses
- Low soil P or high P fixation: capital investments
- FBMP for specific characteristics of crops, cropping systems, environments and soils

Potassium

- Great diversity in K budgets
- Target AE_K: 10-20 kg grain/kg K applied. Typically, this requires an RE_K of 0.4-0.6 kg/kg.
- Eliminate other factors that cause low K use efficiency
- Moderate soil K: balance inputs and outputs at field and farm scales
- Low soil K or high K fixation: capital investments
- Maximize internal K recycling
- FBMP for specific characteristics of crops, cropping systems, environments and soils

- Numerous public and private sector technologies, tools, services, and regulations exist
- Proven success in many developed countries:
  - Continuing rise in yields – no/slower rise in fertilizer use
  - Increasing NUE in USA, U.K., France, Germany, Japan
  - Decreasing nutrient surpluses in Western Europe
- How can we transfer these experiences to the developing world, where needs and means differ?
  - Increase fertilizer use in Sub-Saharan Africa
  - Increase N use efficiency in Asia
  - Improve balanced crop nutrition everywhere
  - Address specific issues: micronutrients, environmental pollution



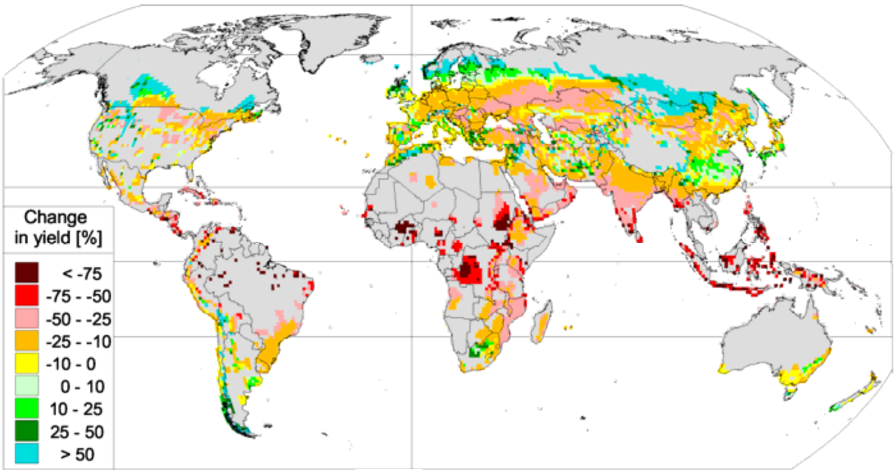
Land use patterns are changing dramatically

- Urbanization
- Economic growth
- Deforestation
- Water shortages
- Changes in dietary preferences
- Biofuels
- Climate change

How will this affect FBPM?

A warmer, dryer and yet wetter world

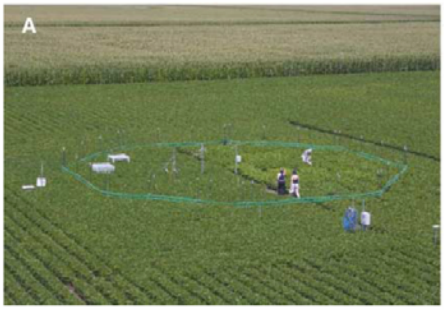
Predicted effect of climate change on potato yields by 2050

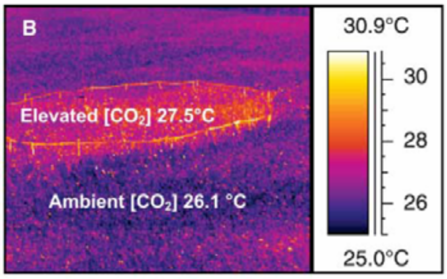


Negative where it is a staple for the poor

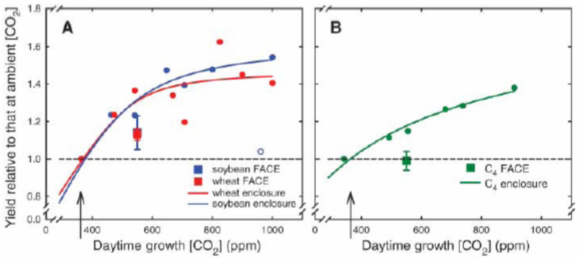
CIP / R. Hijmans

Smaller than predicted CO_2 fertilization effect





Lower stomatal conductance at high CO_2 – less ET
Role of K in this???



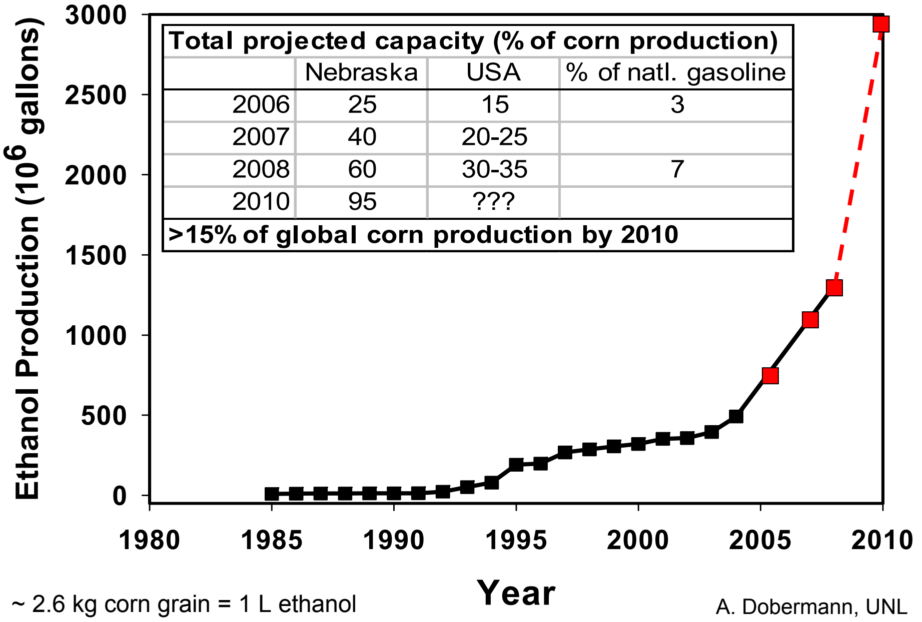
S. Long et al., Science, 2006

- Tolerate high T:
  - Engineer new varieties that are more tolerant to high T at flowering or shed pollen earlier during the day when it is cooler (likely)
  - Engineer new varieties that have lower maintenance respiration rates under warm conditions (uncertain)
- Escape or avoid high T:
  - Shift planting to cooler periods or grow varieties with shorter/longer duration to escape heat periods (possible in some areas)
  - Change other crop management practices to create "cooler" canopies (uncertain).
- **FBMP** for crop adaptation to climate change?

GHG mitigation options for agriculture

- Reduce emissions
  - Management changes to reduce fluxes of CO_2, N_2O, and CH_4 in crop and livestock production → **FBMP**
- Enhance net GHG removal
  - Land use change (e.g., agroforestry, forestry)
  - Soil C sequestration (conservation tillage) → **FBMP**
  - Bio-char from crop residues/organic waste
- Displace GHG emissions from fossil fuel
  - Less fossil fuel use due to higher NUE → **FBMP**
  - Fossil fuel offset by using biofuels → **FBMP**

Annual Nebraska Ethanol Production



Total projected capacity (% of corn production)			
	Nebraska	USA	% of natl. gasoline
2006	25	15	3
2007	40	20-25	
2008	60	30-35	7
2010	95	???	
>15% of global corn production by 2010			

~ 2.6 kg corn grain = 1 L ethanol

A. Dobermann, UNL

- Impact on fertilizer demand? **FBMP for biofuel systems**?
  - Increase in agricultural area
  - High grain prices - incentive for high yields and high N use
  - Shift to more fertilizer-intensive crops: e.g., corn (N), oil palm (K, Mg)
  - Depletion of SOM, K, other nutrients due to biomass removal
  - P concentration in by-products – livestock cycle

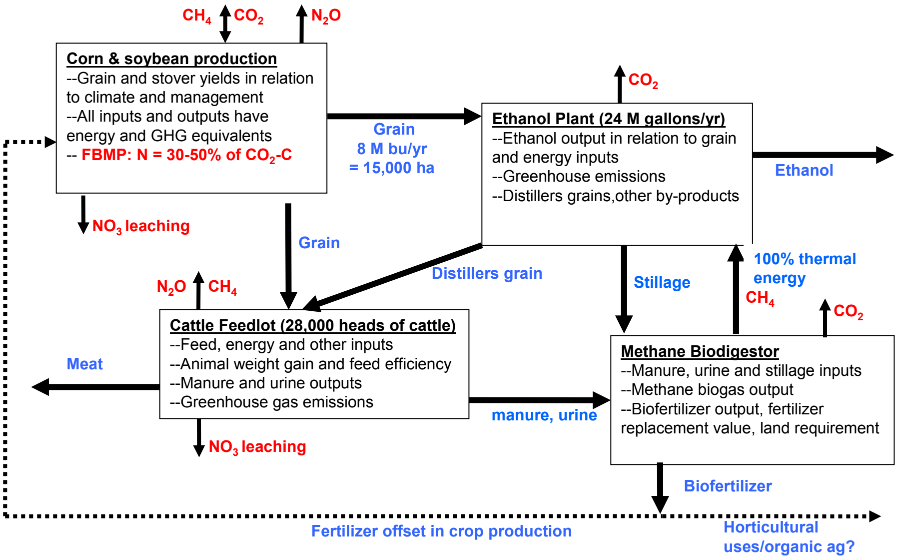
Terry Klopfenstein, Animal Science
Univ. of Nebraska

Distillers Grains

10 kg corn grain feedstock result in about 3.3 kg DDG
30% CP(65% UIP), 11% fat, 40% NDF
High fiber energy source with high digestibility
Energy content - 125% (wet or dry) of corn
Phosphorus content - 0.5 to 1% P
Sulfur content - 0.35 to 1.0%, variable

First Commercial-Scale Closed Loop Biofuel Refinery, Mead, Nebraska

www.e3biofuels.com



CH_4 CO_2 N_2O

Corn & soybean production
--Grain and stover yields in relation to climate and management
--All inputs and outputs have energy and GHG equivalents
-- FBMP: N = 30-50% of CO_2-C

NO_3 leaching

Grain
8 M bu/yr
= 15,000 ha

CO_2

Ethanol Plant (24 M gallons/yr)
--Ethanol output in relation to grain and energy inputs
--Greenhouse emissions
--Distillers grains,other by-products

Ethanol

Grain

Distillers grain

Stillage

100% thermal energy

CH_4

CO_2

N_2O CH_4

Cattle Feedlot (28,000 heads of cattle)
--Feed, energy and other inputs
--Animal weight gain and feed efficiency
--Manure and urine outputs
--Greenhouse gas emissions

Meat

NO_3 leaching

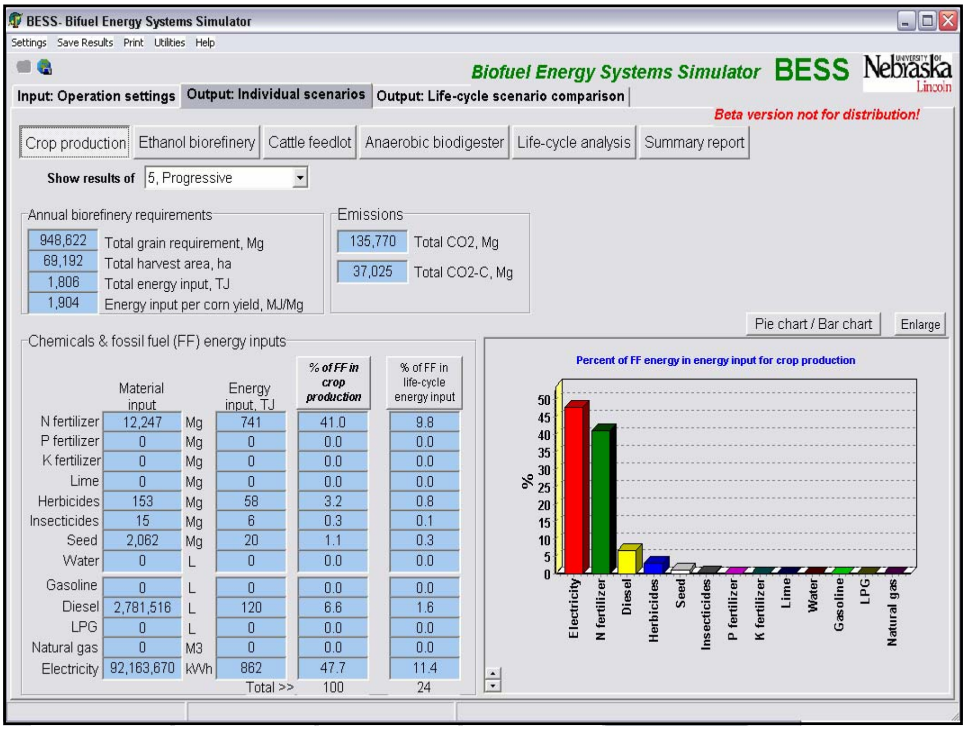
manure, urine

Methane Biodigestor
--Manure, urine and stillage inputs
--Methane biogas output
--Biofertilizer output, fertilizer replacement value, land requirement

Biofertilizer

Fertilizer offset in crop production

Horticultural uses/organic ag?



Show results of 5, Progressive

Annual biorefinery requirements

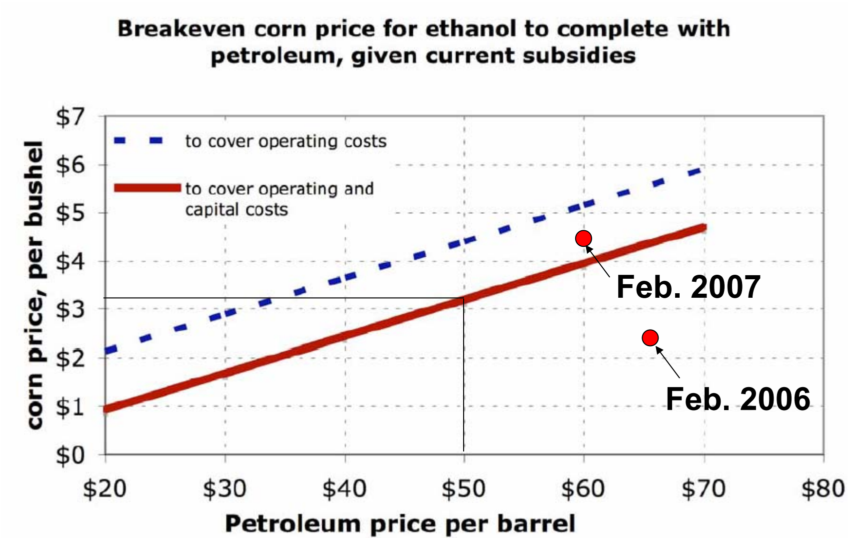
948,622	Total grain requirement, Mg
69,192	Total harvest area, ha
1,806	Total energy input, TJ
1,904	Energy input per corn yield, MJ/Mg

Emissions

135,770	Total CO2, Mg
37,025	Total CO2-C, Mg

Chemicals & fossil fuel (FF) energy inputs

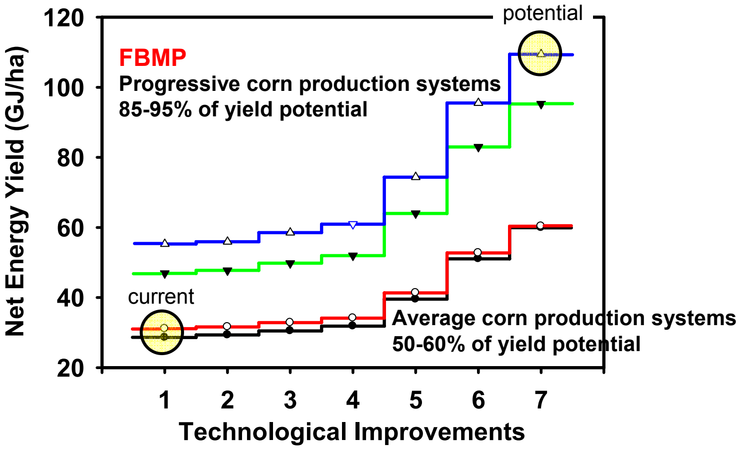
	Material input		Energy input, TJ	*% of FF in crop production*	% of FF in life-cycle energy input
N fertilizer	12,247	Mg	741	41.0	9.8
P fertilizer	0	Mg	0	0.0	0.0
K fertilizer	0	Mg	0	0.0	0.0
Lime	0	Mg	0	0.0	0.0
Herbicides	153	Mg	58	3.2	0.8
Insecticides	15	Mg	6	0.3	0.1
Seed	2,062	Mg	20	1.1	0.3
Water	0	L	0	0.0	0.0
Gasoline	0	L	0	0.0	0.0
Diesel	2,781,516	L	120	6.6	1.6
LPG	0	L	0	0.0	0.0
Natural gas	0	M3	0	0.0	0.0
Electricity	92,163,670	kWh	862	47.7	11.4
			Total >>	100	24



Breakeven corn price for ethanol to complete with petroleum, given current subsidies

Petrol @ $50/barrel:
- to be competitive with gasoline ethanol needs to sell for $1.55/gal (incl. $0.51/gal subsidy)
- Plant operating costs $0.55/gal + $0.30/gal capital cost - $0.10/gal federal subsidy
- max. corn price to break even: $1.55 – 0.85 + 0.10 = 0.80/gal = $3.20/bushel

R. Perrin, University of Nebraska, February 2007



Impact of technological improvements on net energy yield of corn-ethanol systems. Black: Farrell *et al.* 2006 (1), Red: rf-NT, Green: irr-NT, Blue: irr-CT. Technological Improvements: 1) crop management (current base scenario), 2) N-fertilizer efficiency, 3) crop genetics, 4) ethanol conversion efficiency, 5) non-drying distiller's grains, 6) closed-loop biorefinery, 7) cumulative impact of all improvements (1-6)

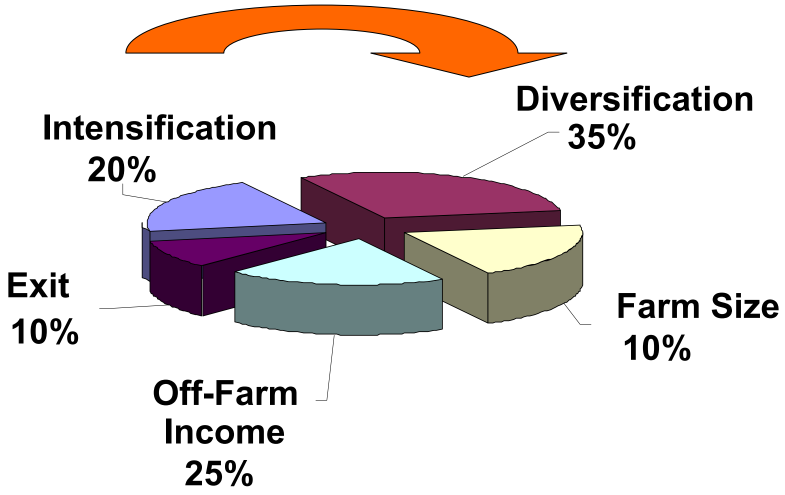
A. Liska et al. University of Nebraska, 2007

Cereal production landscapes: FBMP for maintaining sustainability and ecosystem services during intensification and/or diversification

Nearly half of the world's rice is produced in irrigated monoculture

Household poverty escape pathways

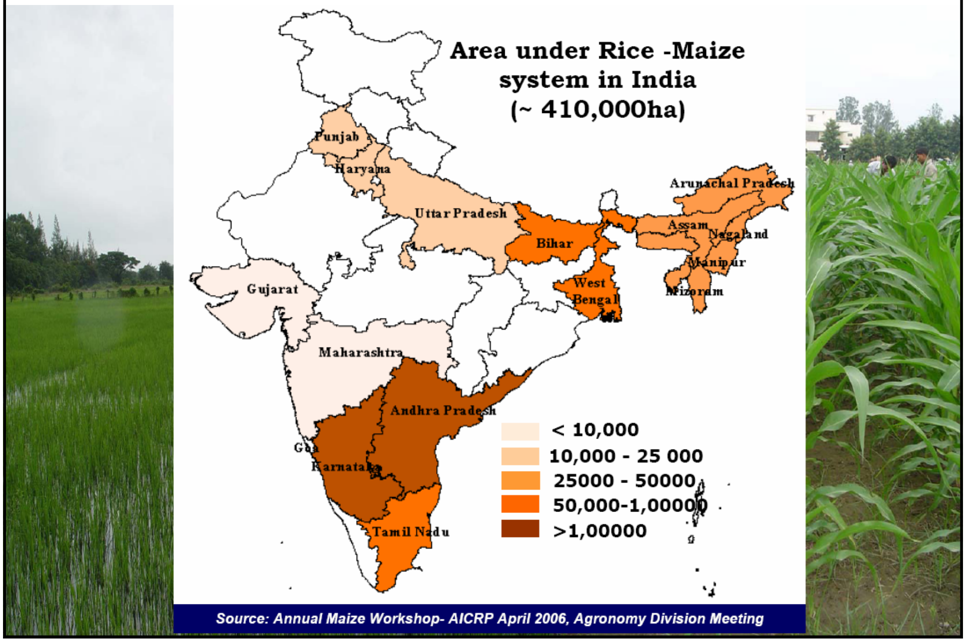
e.g., rice-wheat farming system, South Asia



Source: J. Dixon, CIMMYT

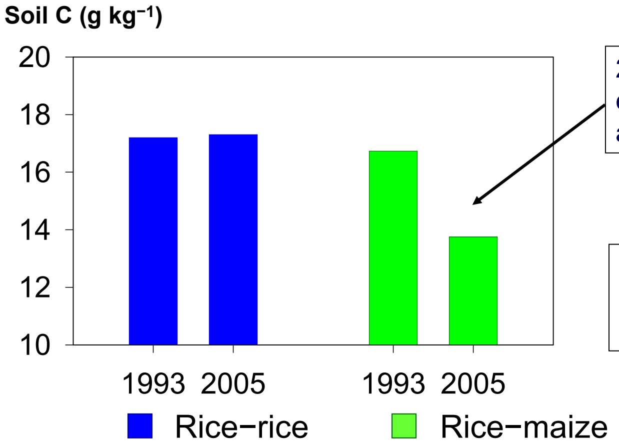
Rice-maize in India

Source: P. Zaidi (ICAR)



Source: Annual Maize Workshop- AICRP April 2006, Agronomy Division Meeting

Decrease in soil C 12 years after conversion from continuous rice to a rice-maize rotation, IRRI, Los Banos, Philippines

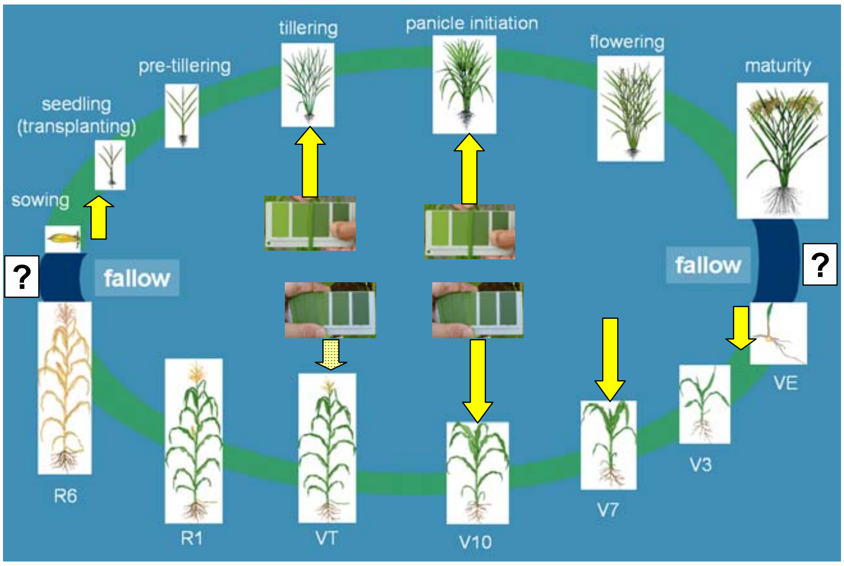


25% of soil carbon to atmosphere

What is happening to nitrogen?

Converting a carbon sink into a carbon source?

R Buresh/IRRI

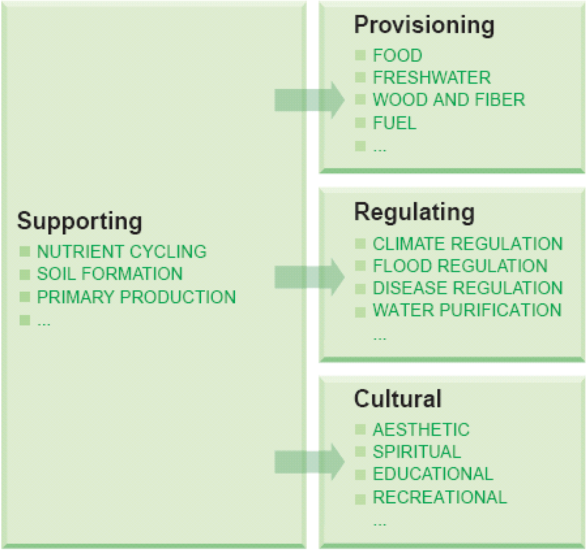


Site-specific nutrient management for ***cropping systems***

C. Witt (IPNI & IPI), R. Buresh (IRRI), and A. Dobermann

Ecosystem Services

The benefits people obtain from ecosystems



Supporting
- NUTRIENT CYCLING
- SOIL FORMATION
- PRIMARY PRODUCTION
- ...

Provisioning
- FOOD
- FRESHWATER
- WOOD AND FIBER
- FUEL
- ...

Regulating
- CLIMATE REGULATION
- FLOOD REGULATION
- DISEASE REGULATION
- WATER PURIFICATION

...

Cultural
- AESTHETIC
- SPIRITUAL
- EDUCATIONAL
- RECREATIONAL

...

Indicators?
Management practices?
Policies?
Who pays for what?
Monitoring?

Millennium Ecosystems Assessment

Old and new global food and nutrition problems

Type	Causes	People affected
Hunger	Deficiency of calories and protein	0.9 billion
Children underweight	Inadequate intake of food and frequent disease	126 million
Micro-nutrient deficiency	Deficiency of vitamins and minerals	More than 2 billion
Overweight to chronic disease	Unhealthy diets; Lifestyle	Increasing also among the poor

Joachim von Braun, CGIAR, AGM06

New paradigm for overcoming malnutrition

1. Balance crop nutrition to increase crop yields: sufficient staple produced on less land
2. Devote remaining land to more nutrient-dense and nutrient-balancing crops
3. Address additional requirements of humans and animals for vitamins, Zn, Fe, B, Se, and I
    - Biofortification (genetic or agronomic approaches)

- **FBMP:**
    - Local FBMP for micronutrient management, including fertilizer fortification with micronutrients (Zn, Se, B) where feasible and supported by policies
    - FBMP for genetically biofortified crops - interactions
- Demonstrate in large-scale case studies: Africa, S. Asia

Graham et al., Adv. Agron., 2007

Ecological Intensification of Cereal Production

- High and sustainable food/feed/biofuel production and profit
- Yields within 80-90% of climatic, seasonal yield potential
- In irrigated systems: >80-90% water use efficiency
- 50-80% N fertilizer uptake efficiency (RE_N)
- Balanced supply & budgets of nutrients, max. internal recycling
- Resilient to abiotic stress: drought & heat
    - Germplasm improvement and conservation agriculture
- Resilient to biotic stresses
    - Germplasm improvement (host plant resistance) & IPM
- High-quality harvest products: grain quality, nutrition, specialty traits for industry
- Low global warming potential
- Positive energy balance – high net energy yield
- Maintain/improve ecological services