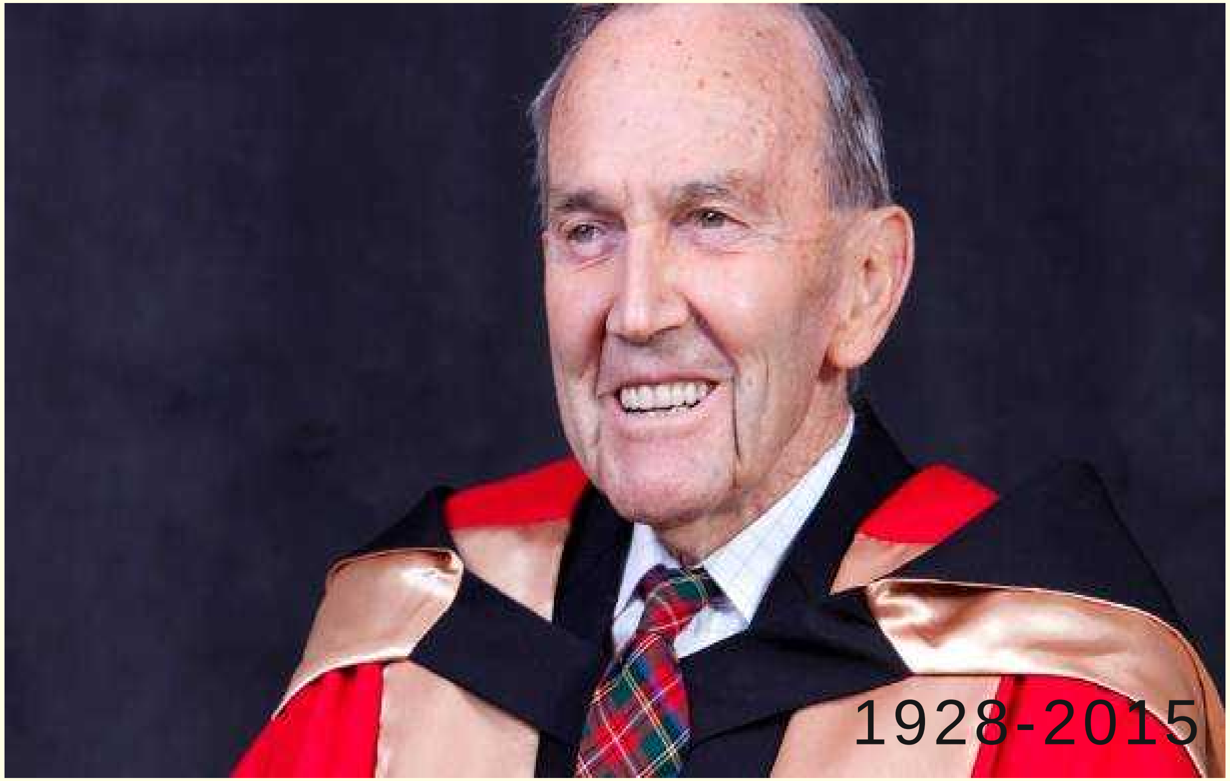
John Freney Memorial Session



Nitrogen in Cereal Production: Opportunities for Enhanced NUE and Reduced Losses

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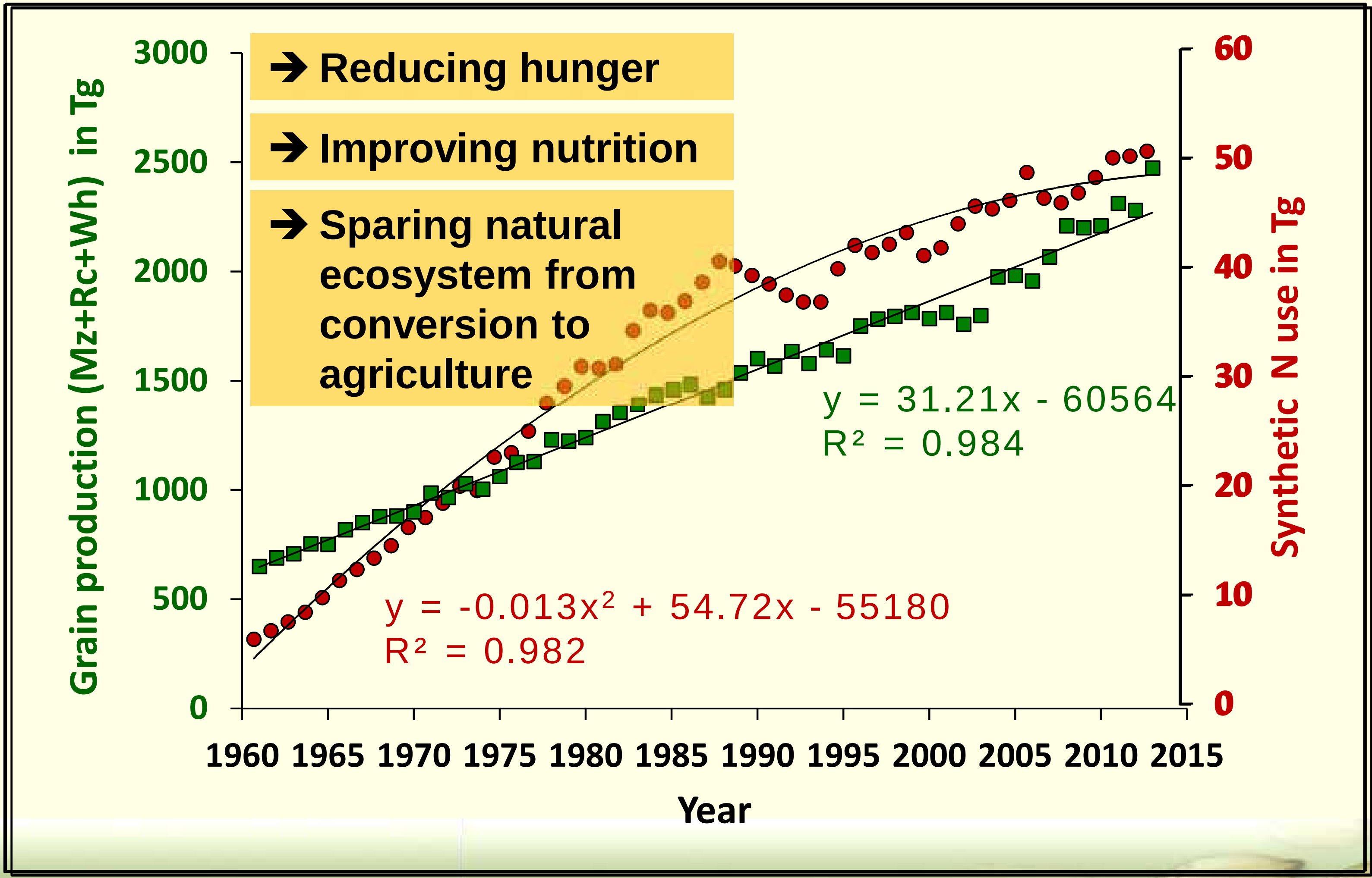
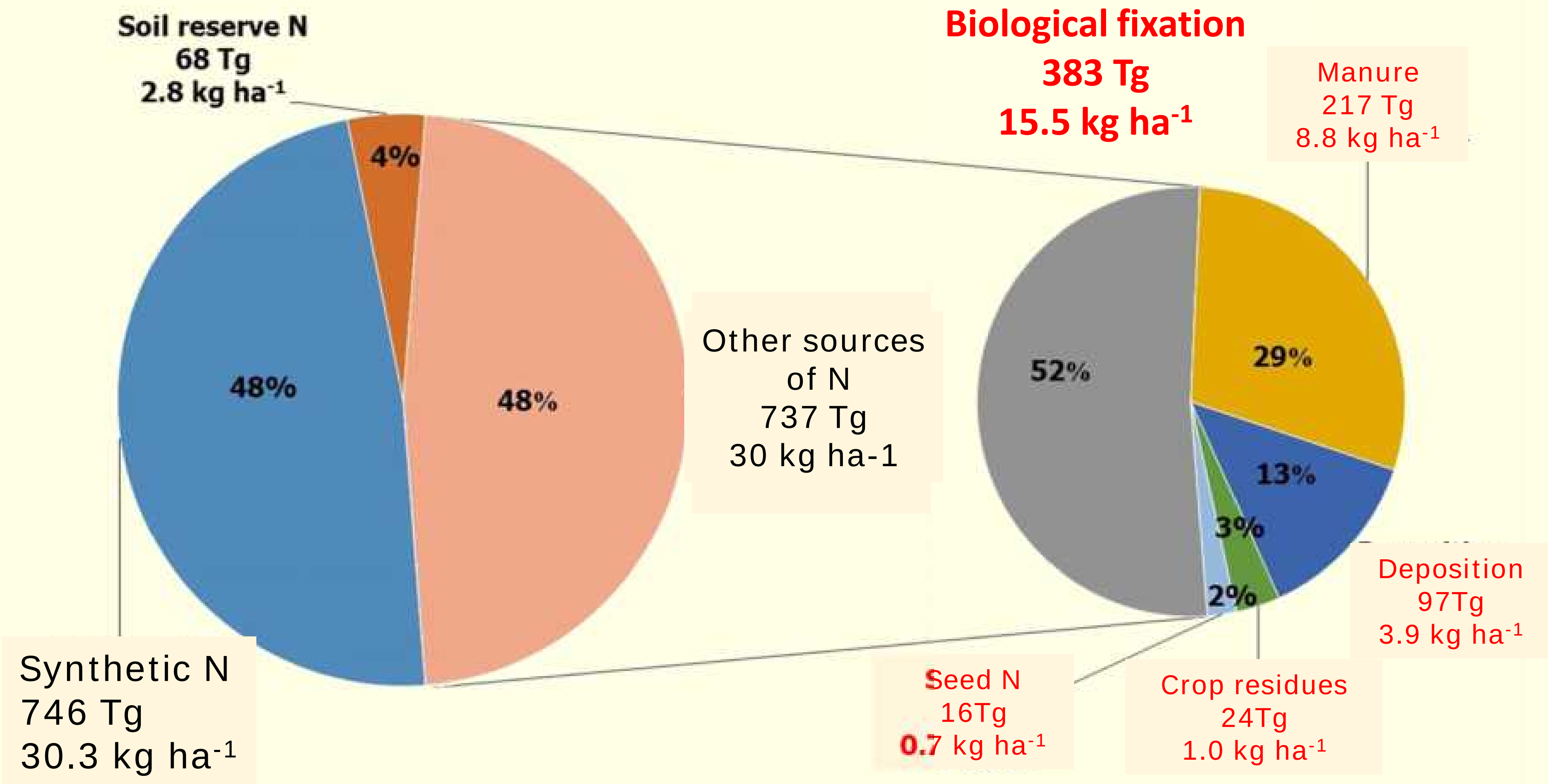
Outline

- Synthetic N and cereal production
- Other sources of N
- NUE – a ratio with multiple terms
- Strategies to improve NUE
  Agronomy and genetic
- Sine qua non

Global Grain Production and Use of Synthetic N (Maize + Rice + Wheat)



A 50-Yr Top-Down Global N Budget of Maize, Rice Wheat



Environmental Challenge – N Leakesges

Losses from synthetic N 847 Tg

Losses from other sources of N 790 Tg

Ladha et al 2016

How to improve NUE?

- How do we define NUE?
- What are the causes of poor NUE?
- What are the strategies?

Nitrogen Use Efficiency Terms

Indices/Targets

1. NUE = N Output/N Input:
   Agricultural Efficiency
2. N_{sup} (N surplus) = N Input – N Output:
   Environmental Pollution
3. N_{yield} = N Output:
   Food Security

RE_N (total N)

RE_N (synthetic N)

N_{sup} (total and synthetic N)

N_{yield} (total and syntheticN)

Zhang et al 2015; EU N Expert Panel 2015

Ratio

Synthetic + Other

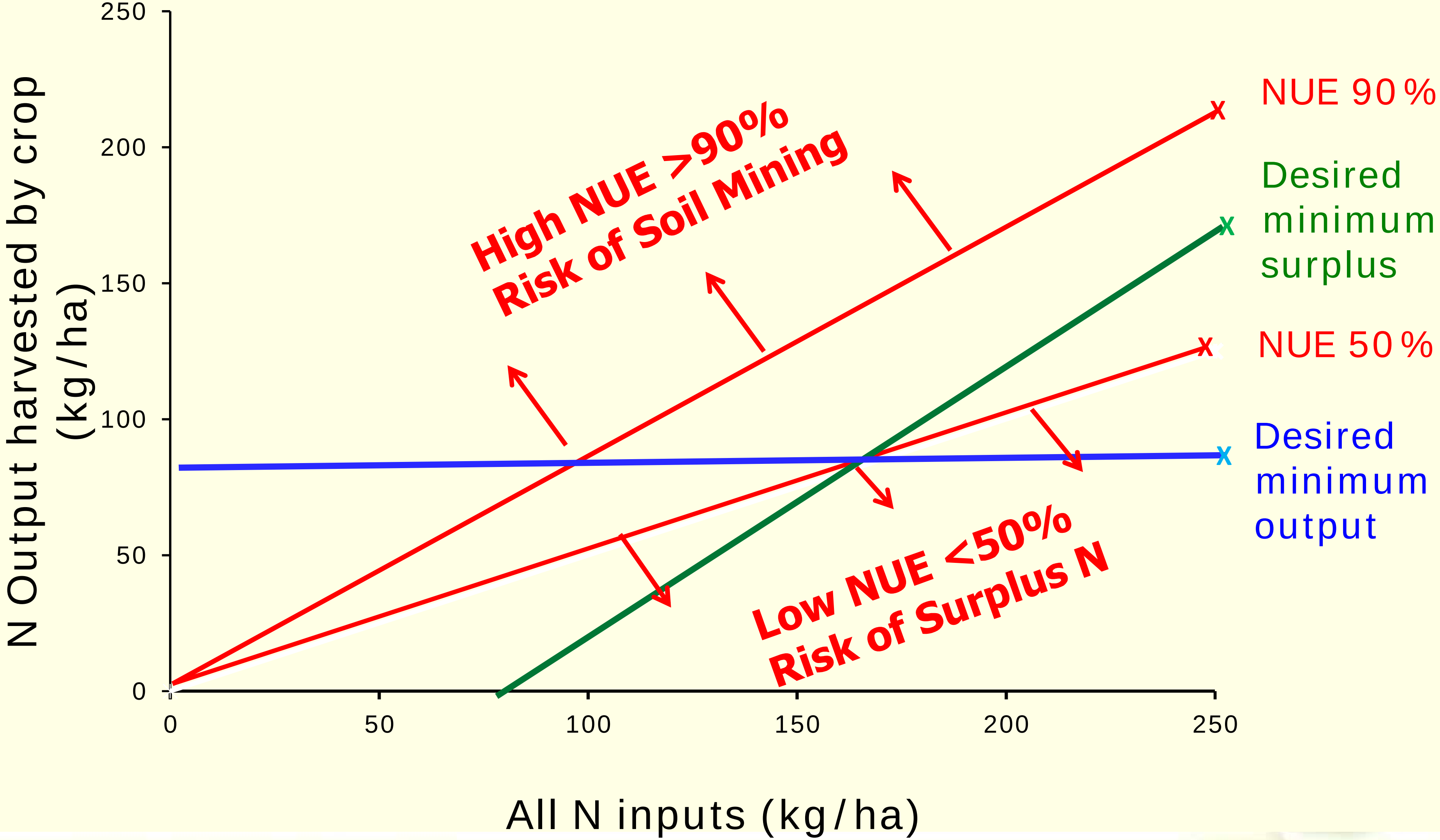
AE_N = kg grain increase/kg synthetic N

RE_N = kg plant N increase/kg synthetic N 3

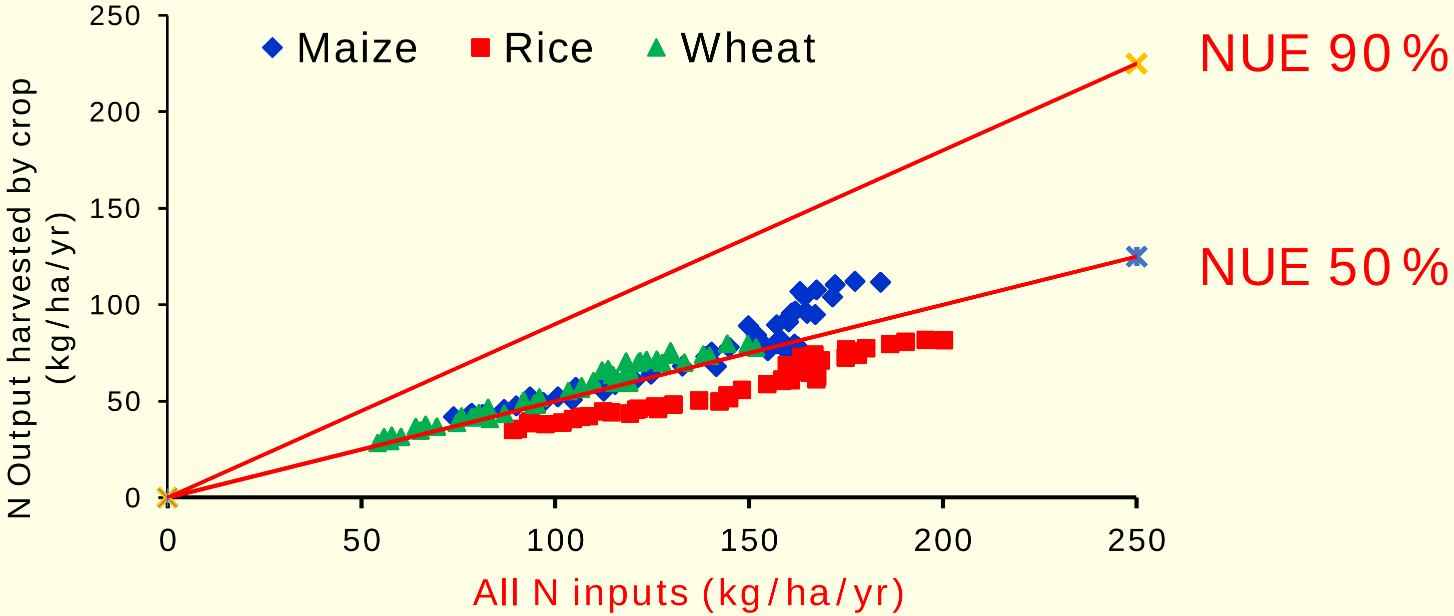
PE_N = kg grain increase/kg plant N

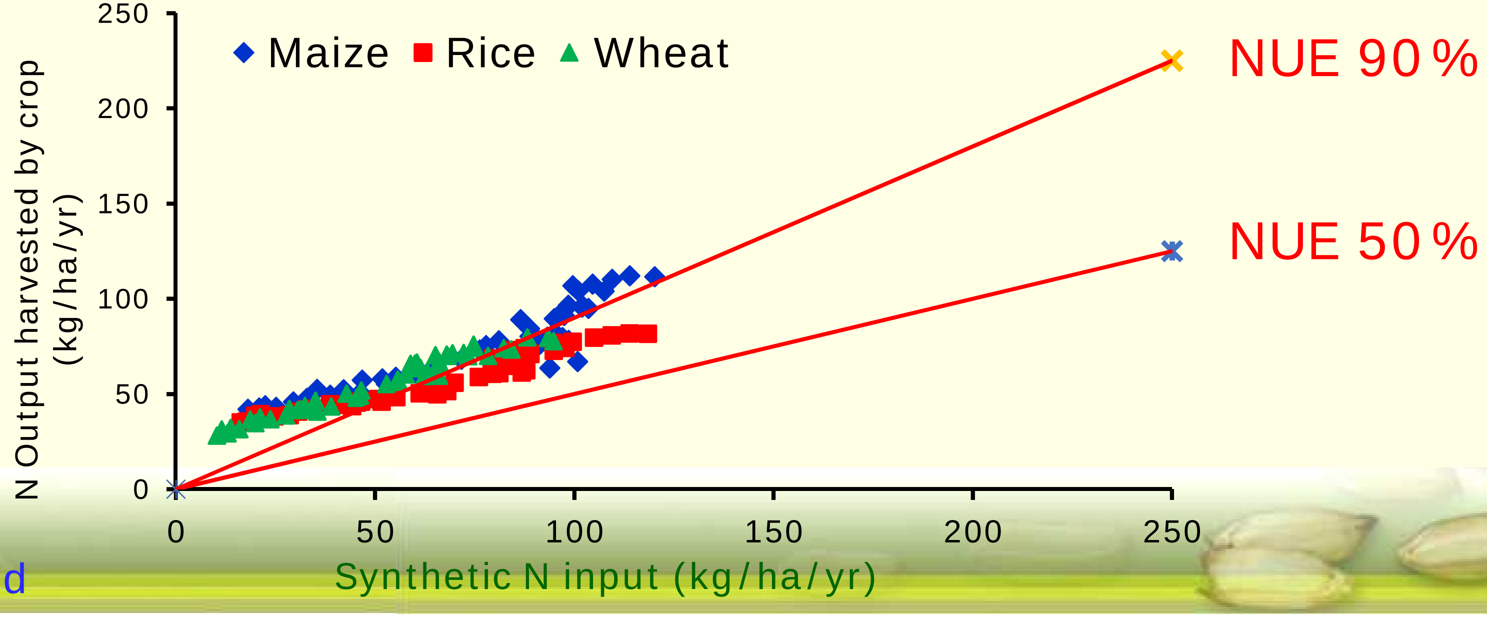
Ladha et al 2005

A Conceptual Framework of NUE Indicator



Framework of NUE Indicator – Global M,R, W Data





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Reasons of Poor NUE

1. Dynamic nature of N

2. Deteriorating soil quality as medium to regulate N supply

3. Poor agronomy

4. Misuse or excess use of N
   - lack of awareness
   - subsidy

How to Improve N Use Efficiency and Minimize N Leakages?

Volatilization and emission of N gases

Plant N Demand

Soil N Supply

Leaching and runoff of N

Synchronize in time-space

Irradiance, temp, water, pests/diseases, nutrients, cultivar

NCE - grain and biomass

N acquisition

Synthetic N
BNF
Manure/residue
Deposition

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Strategies to Improve NUE

Resource Management

Synthetic N – 4Rs

- Right time
- Right rate
- Right place
- Right source

Soil or other sources of N

- Optimizing lignin/N

Best Management

Genetic Manipulation

Crop Breeding

- High yield potential, HI and NHI

Genetic Engineering

- Acquisition
- Usage pattern

N_2 fix-symbiosis

Targeting Potential Yield

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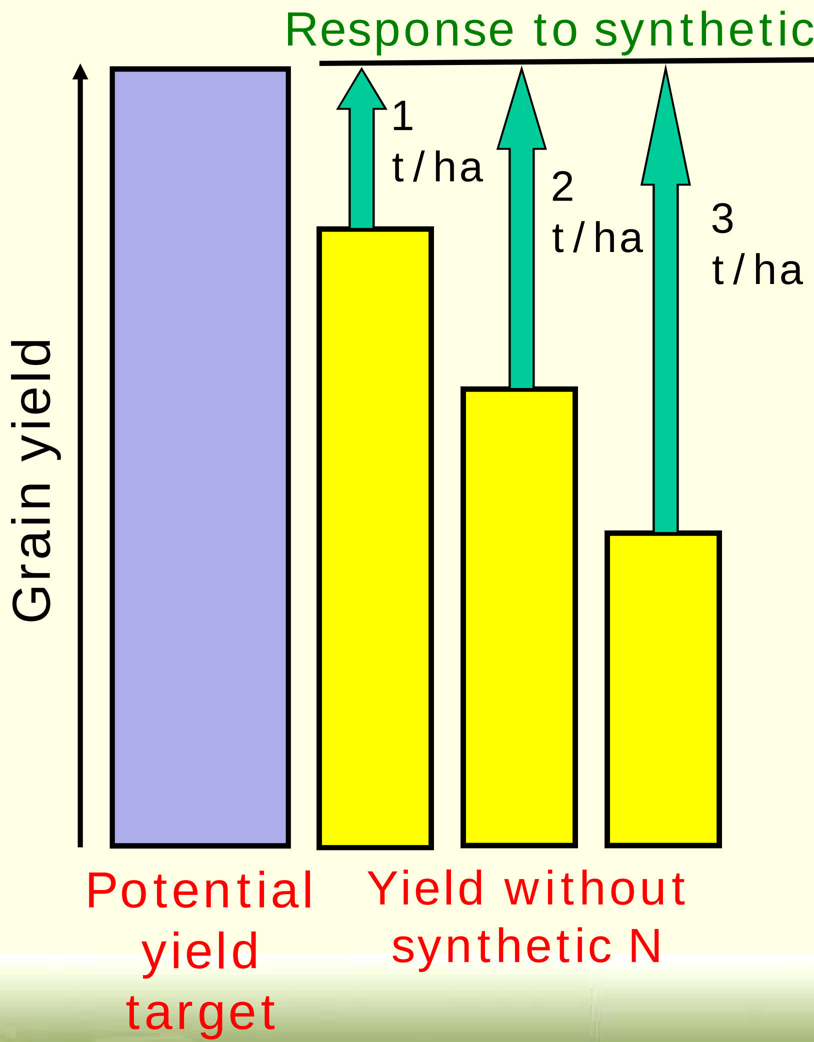
Consider Soil N Supply and Estimate Response to Synthetic N



N response (t/ha)	Estimate N rate (kg N/ha)	Target AE_N
0.5	30	16
1	55 to 60	16 to 18
2	100 to 110	18 to 20
3	120 to 150	20 to 25

AEN = kg grain increase/kg synthetic N

Buresh

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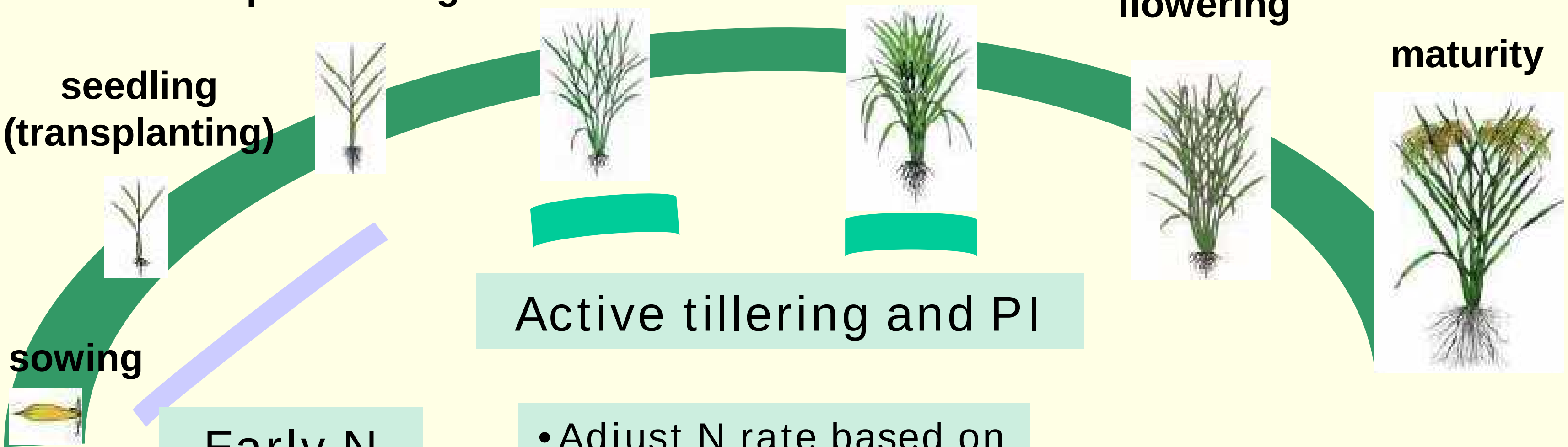
Apply N to Match Crop Demand- Real Time N Management



Early N

- Apply only a moderate amount
- Consider soil N supply in demand

Active tillering and PI

- Adjust N rate based on crop response

- Apply N based on leaf N status
- Achieve optimal LAI and crop canopy

The key is to establish method for rapid diagnosis of leaf N status

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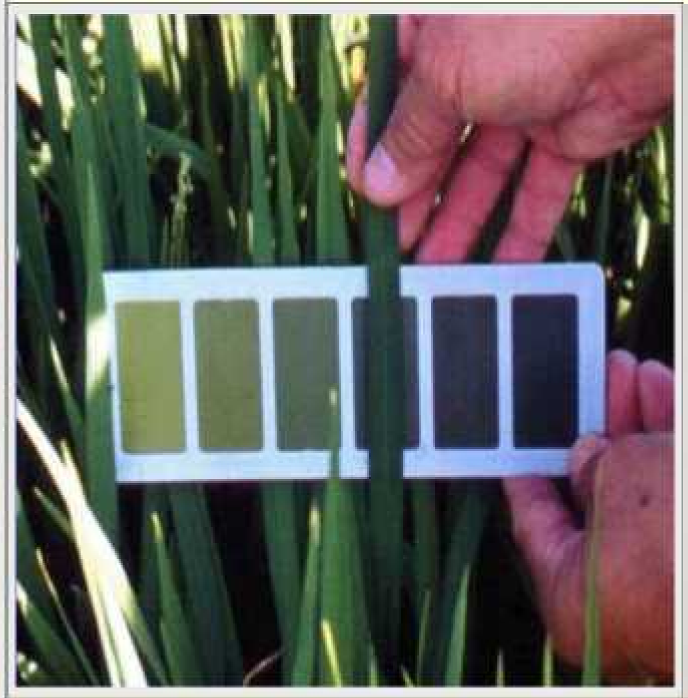
Diagnosis of Leaf N Status



Leaf Color Chart GreenSeeker

SPAD Meter

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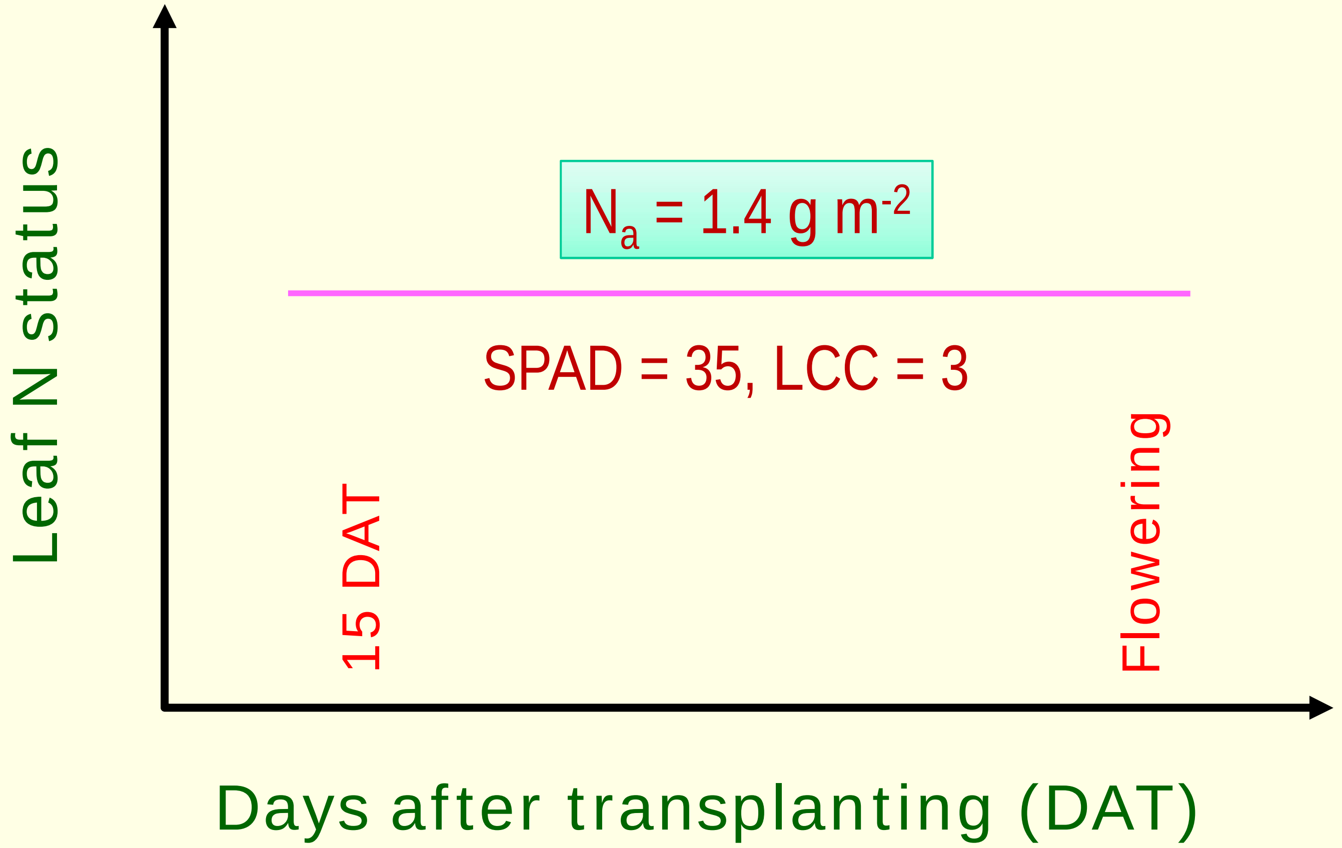
Real-Time N Management with SPAD or LCC



A single SPAD or LCC value could be used as a threshold for timing N topdressing for a given cultivar

Peng et al 1995

LCC, a N Thermometer

- LCC is a N thermometer which tells me when plant need N
- It is simple and has increased my knowledge about N
- This allows me to control excess or misuse of N

Seed-cum Fertilizer Drills: N Management with CA

System Optimization for High Potential Yields

Maize – USA

Grassini and Cassman 2012 PNAS

Maize, Rice and Wheat – China

Chen and Fan 2014 Nature

Maize, Rice and Wheat – South Asia

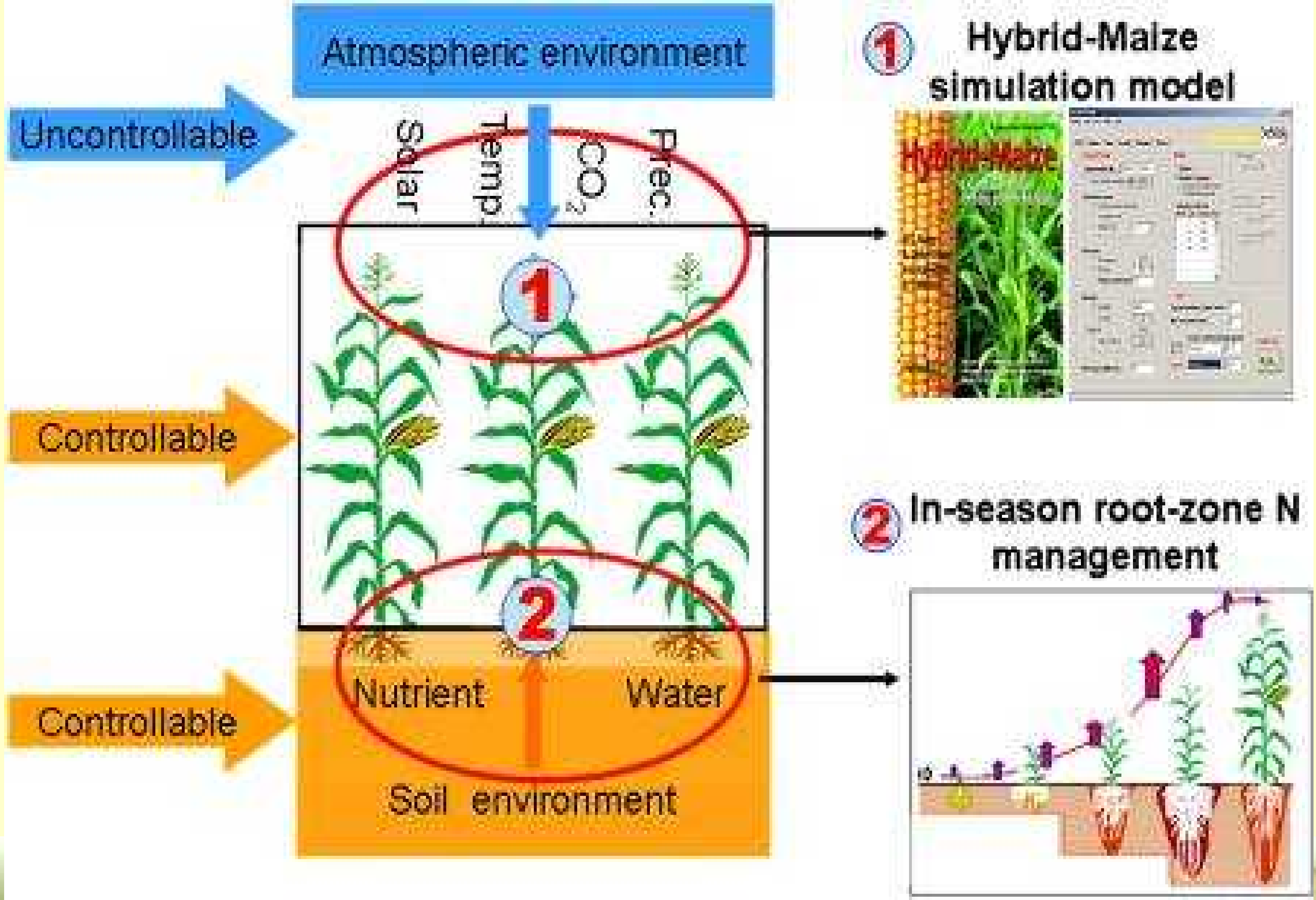
Ladha et al 2016 Global Change Biology

Rice – Uruguay

Pittelkow et al 2016 Global Food Security

ISSM – Example of Synchronizing N Supply with Crop Demand Through Targeting High Yield

Combining planting crop traits to optimize capture of favorable growing conditions and crop N requirements in time, space, and quantity



Chen et al 2011

Crop Management (Integrated Soil Crop System Management) – Rice, Wheat and Maize, China

Crops	Treatment	Yield (Mg ha^{-1})	N rate (kg N ha^{-1})	PFP$_N$ (kg kg^{-1})	N surplus (kg N ha^{-1})
Rice					
	Current practice	7.2	181	41	58
	ISSM	8.5	162	54	16
	Farmers' practice (n = 6,592)	7.0	209	41	82
Wheat					
	Current practice	7.2	257	28	74
	ISSM	8.9	220	41	2
	Farmers' practice (n = 6,940)	5.7	210	33	74
Maize					
	Current practice	10.5	266	40	72
	ISSM	14.2	256	56	8
	Farmers' practice (n = 5,406)	7.6	220	43	72

Chen et al 2014

Strategies to Improve NUE

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Targeting Potential Yield

Ladha et al 2005

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NUE Improvement - Crop Breeding

Major Conclusions

- N acquisition and NCE (or PE_N) are tightly linked with HI (or NHI) and yield potential
- Cultivars with similar HI do have differences in %N in grain and biomass
- Cultivars differ in N acquisition at low levels of available N – useful for low input agriculture

  $$NPI = GY_0 \times PE_N$$

- Large G X E specially at high levels of synthetic N supply

Ladha et al 1997; Singh et al 1998

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NUE Improvement – Genetic Engineering

QTL Mapping

Gene identification

Gene Engineering

N metabolism

- NR
- GS
- GOGAT

Amino acid biosynthesis

- GDH
- AS
- Ala AT

C/N – PS C metabolism

- Rubisco
- PEPc

McAlister et al 2012

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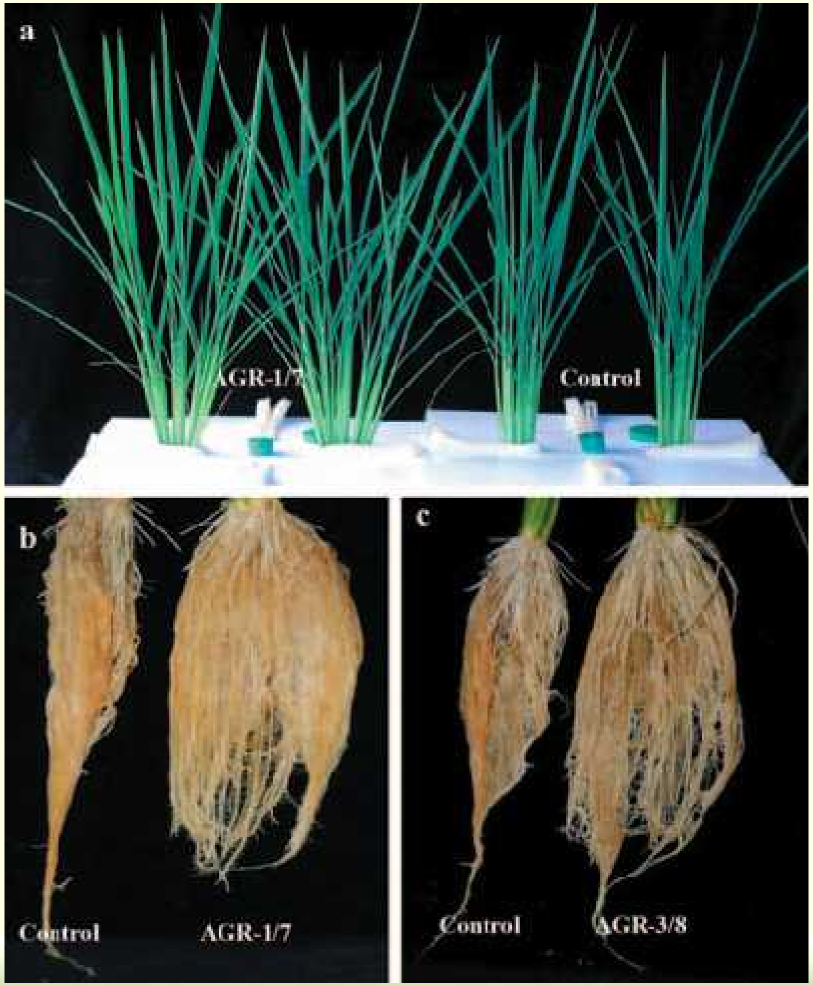
Transgenic Rice over-expressing Alanine Aminotrasferase (AlaAT)



- Transgenic plants produced

(a) bushier, finer and more branched root system with more tillers and vigorous growth, and

(b) higher N uptake during

Hydroponic solution with NH_4-N at vegetative stage

Saharawat et al. 2008

NUE Improvement – Genetic Engineering

Challenges

- Complex quantitative trait
- Difficulty in phenotyping
- QTL analysis is based on yield under low N supply
- Tightly linked with crop yield

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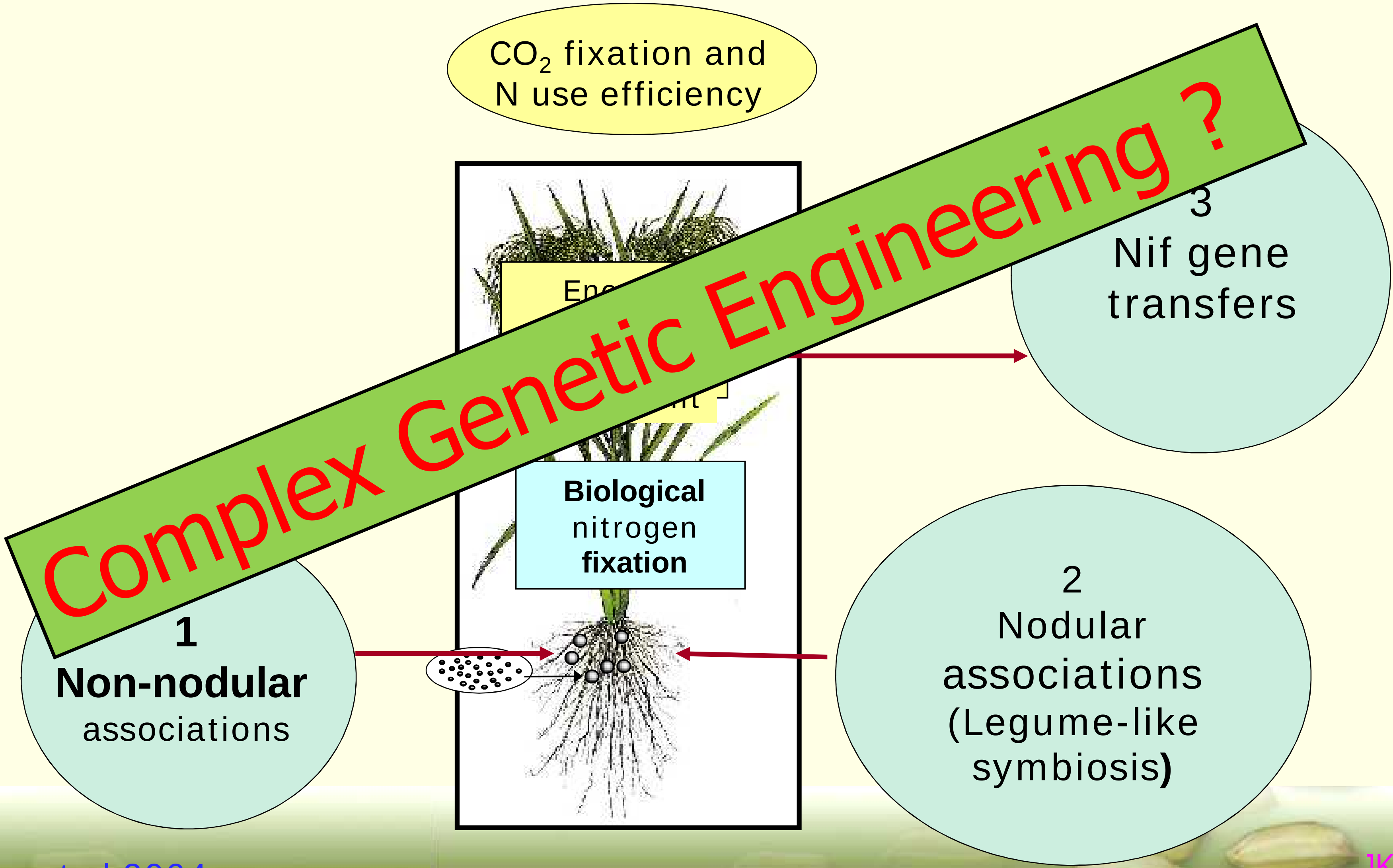
Engineering Cereals to Fix Biological Nitrogen



Ladha et al 2004

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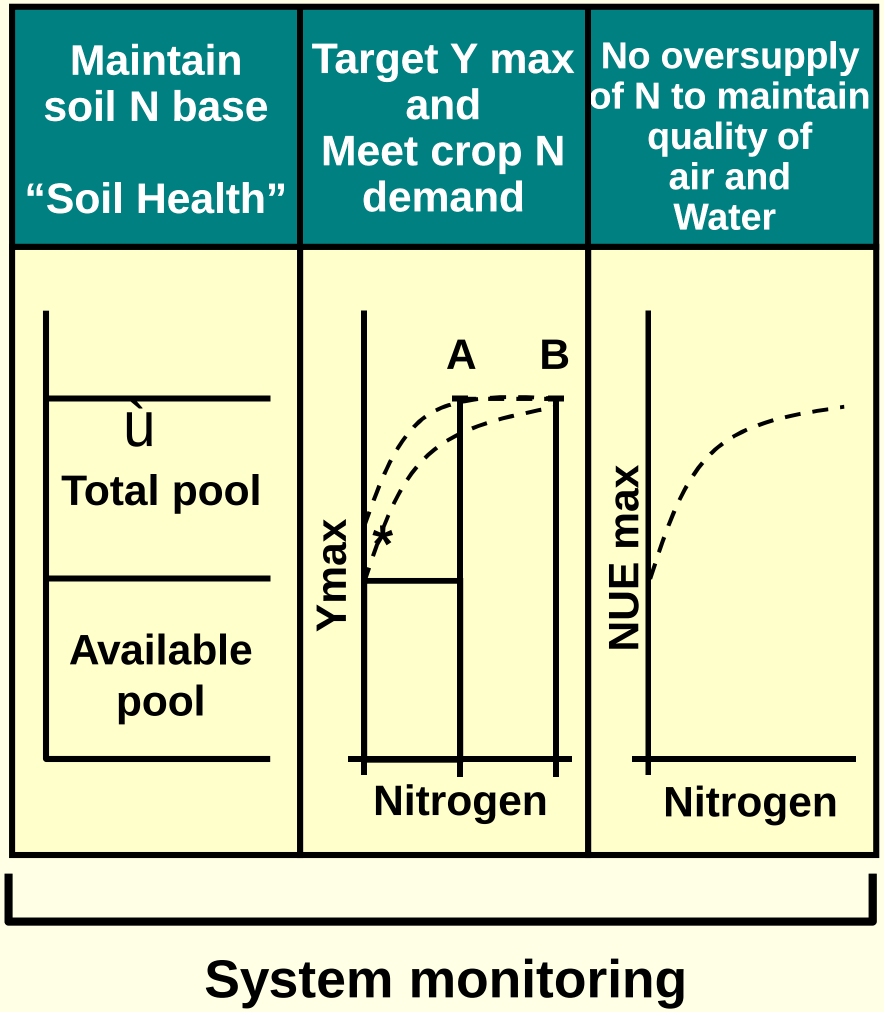
N Sustainability Framework



- ➔ System optimization/agronomy including plant need-based N application
- ➔ Minimize soil disturbance
- ➔ Avoid cycles of soil flooding/drying
- ➔ Avoid dry fallow
- ➔ Practice crop diversity
- ➔ Use quality organic/residue
- ➔ Replenish soil nutrients
- ➔ Deep place N into soil, where applicable

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Sine qua non

Campaign
Awareness
Education

- Best management
  - Crop demand
  - Stimulate BNF/ SON supply
- No overuse
- Multiple splits