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Assessing strategies for efficient and effective nutrient management

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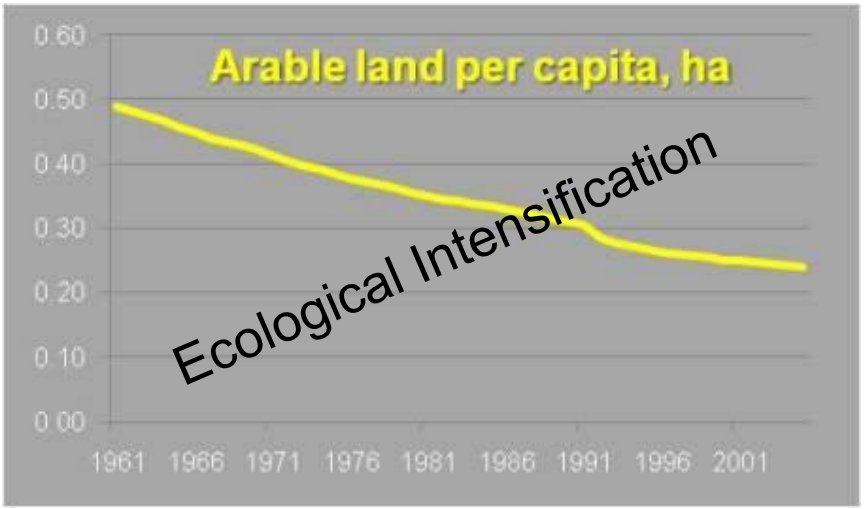
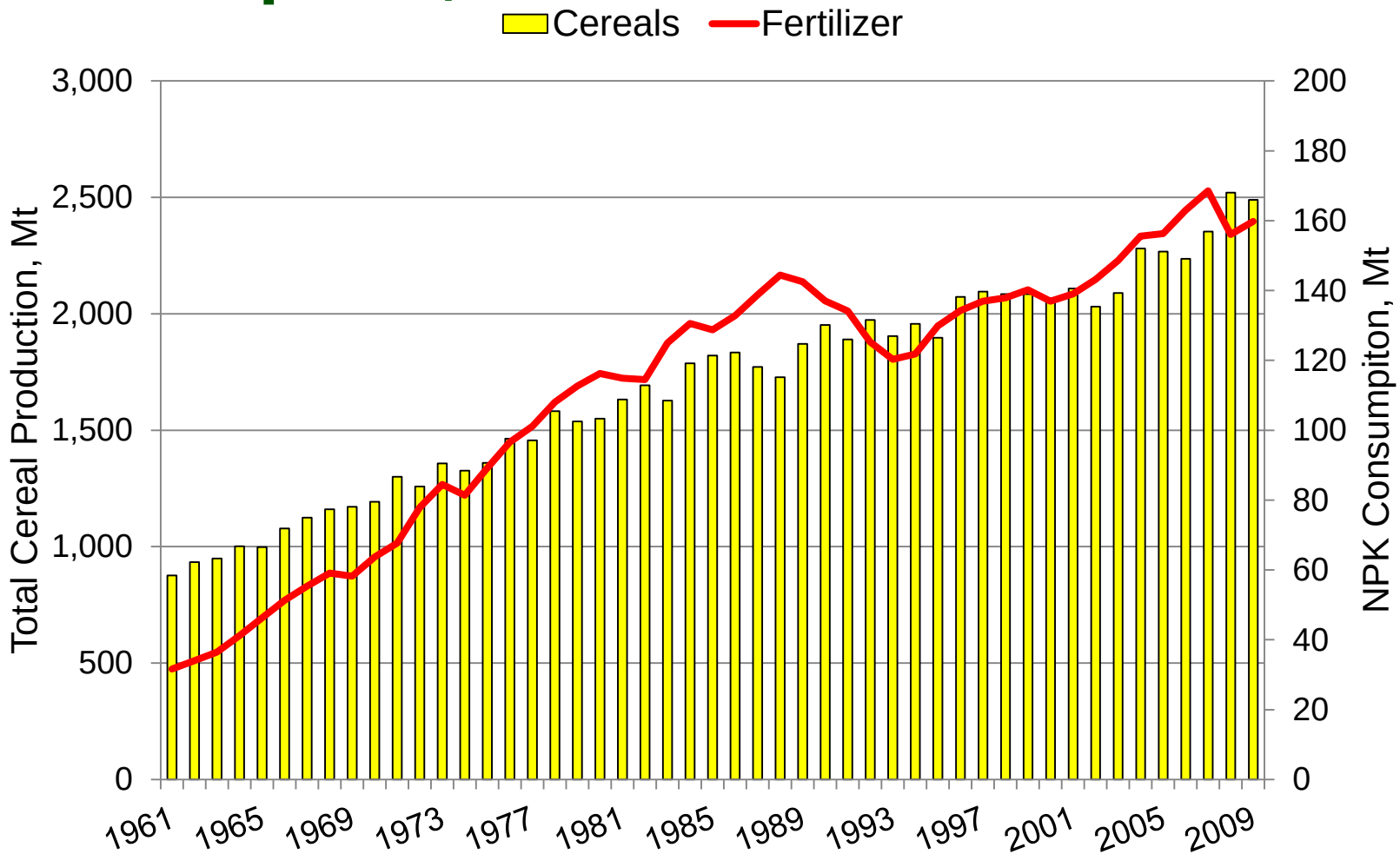
"…food production has to increase 50% by 2013 and double in 30 years…"

(Source: Global Challenges for Humanity, 2008 State of the Future, Millennium Project)

- **Static world land area**
- **Land for nature**
- **Energy & Resource availability**
- **Short term disasters becoming protracted crises**
- **Climate change**



World cereal production and fertilizer consumption, million metric tons



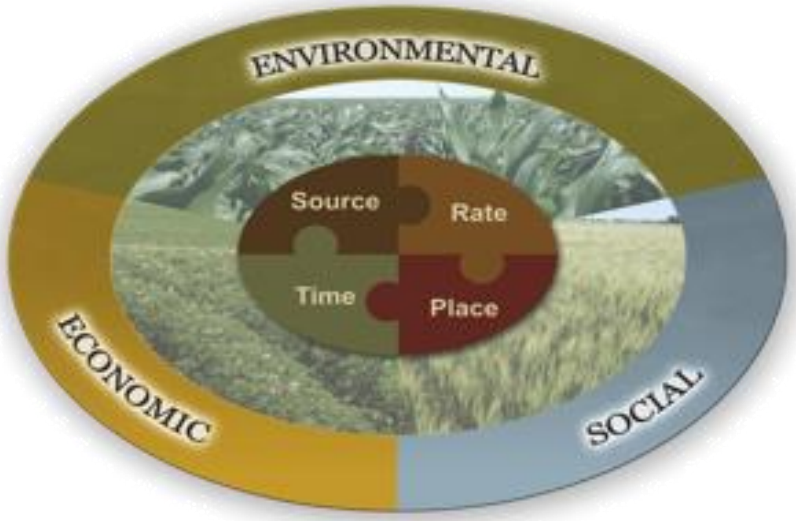
Stewart et al. estimated 40-60% of total food due to fertilizer use.

Source: FAO and IFA

Need for efficiency

- Everyone wants to be efficient
  - Get more production with the same input.
  - Get the same production with less input.
  - Combination of both.

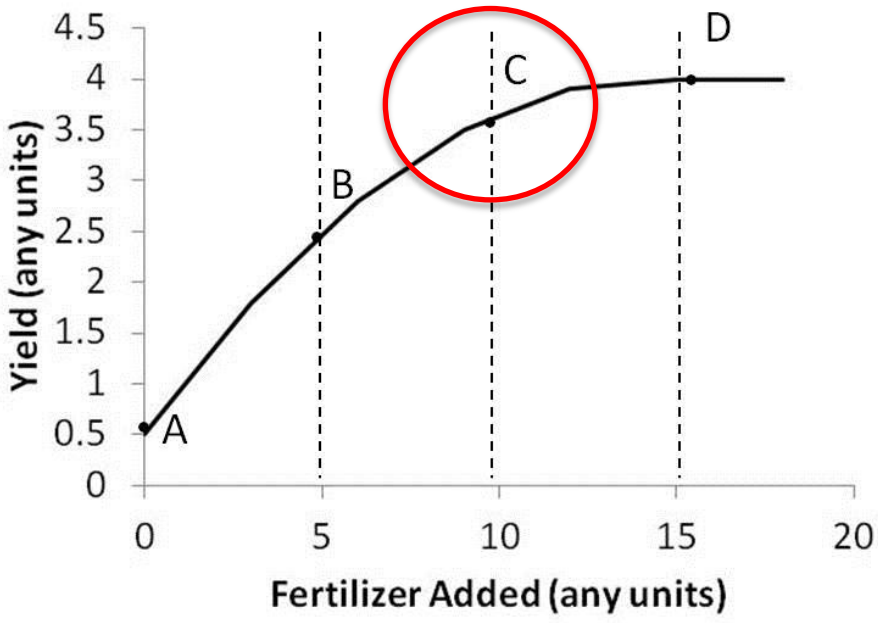
- For nutrient efficient production
  - Minimal loss to the environment
  - Maximal return to the grower
  - Maximum production output
  - *Demonstrate these changes*



- **Green Revolution to the Evergreen Revolution**

Efficiency and Effectiveness

- *Efficiency* and *Effectiveness* are NOT the same



- Before A is the most **efficient** part of the response.
- From A-B-C-D efficiency declines, and effectiveness increases.
- >D is the most **effective** part of the response.

- The best **economic** return is where marginal return is at least equal to marginal cost. *Less than the maximum yield*.

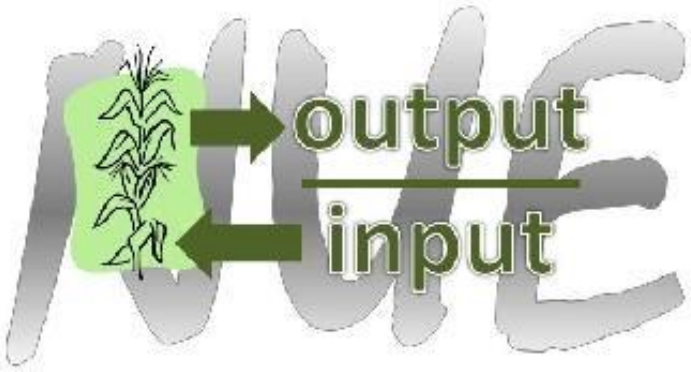
Defining the improvement sought

Enablers (process metrics)

Actions (adoption metrics)

Outcomes (impact metrics)

- **Outcome metrics** – as opposed to *Enabling & Action* metrics which make the *Outcomes* happen.
- There are many metrics that could be appropriate to assess nutrient efficiency outcomes (*ie* benchmarking).



- Numerator
  - output or some configuration of this value
    - Yield, Increased Yield, Nutrient
- Denominator
  - Input or some configuration of this value
    - Fertilizer used, increased fertilizer used.

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Common nutrient use efficiency terminology

NUE term	Calculated from	Typical levels for N (maize or wheat)
Agronomic Efficiency	$(Y-Y_0)/F$	10-30 kg grain/kg nutrient
Recovery Efficiency	$(R-R_0)/F$	33% (grain only) kg grain nutrient/kg nutrient
Partial Factor Productivity	Y/F	40-80 kg grain/kg nutrient
Partial Nutrient Balance *	R/F	>100% = deficiency <100% = surplus kg grain nutrient/kg nutrient

For famers/regions – there is no nil fertilizer (check) plot

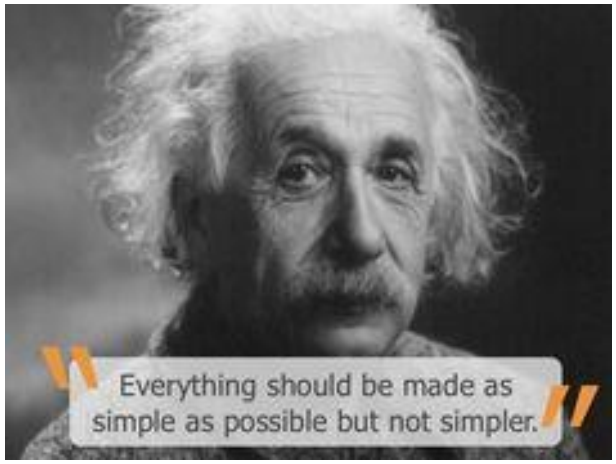
**** PNB = nutrient removal to use ratio***

Y=yield, F=fertilizer, R=removal, U=uptake

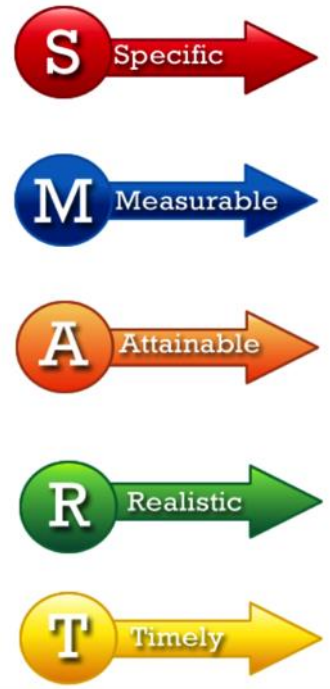
… but always, a ratio of output/input

Dobermann, 2007

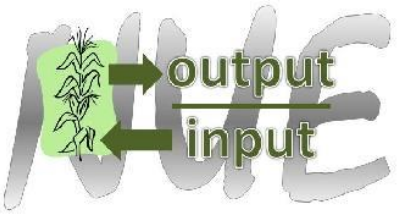
Nutrient Performance Indicators



- Need to be:
  - Systematic in their estimation
  - Scalable
    - Regional, national, global
    - Relevant to farm and field scales also
  - Involve repeated measures over time
    - Every 3 to 5 years: national, regional global
    - Every year: for farms/fields
    - Assess the past and target the future
- Transparent and Traceable
  - Benchmarking for growers to improve management
  - Accountability for regional



Most common indicator….



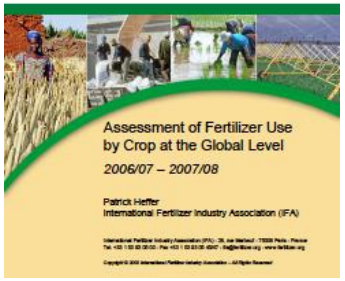
PNB = Nutrient Removal / Fertilizer Nutrient Supplied

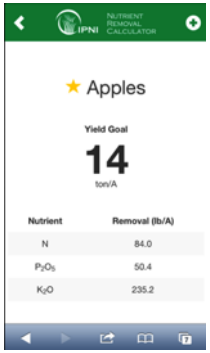
NR = Nutrient concentration
X Product Removal

NS = Fertilizer applied

- **Example of removal to use – for cereals alone**
  - Audit period 2006/7 & 2010
  - Cereals – derived from FAOStats
  - Fertilizer use derived from IFA FUBC data from the above
  - Nutrient concentrations from IPN Database

FAOSTAT





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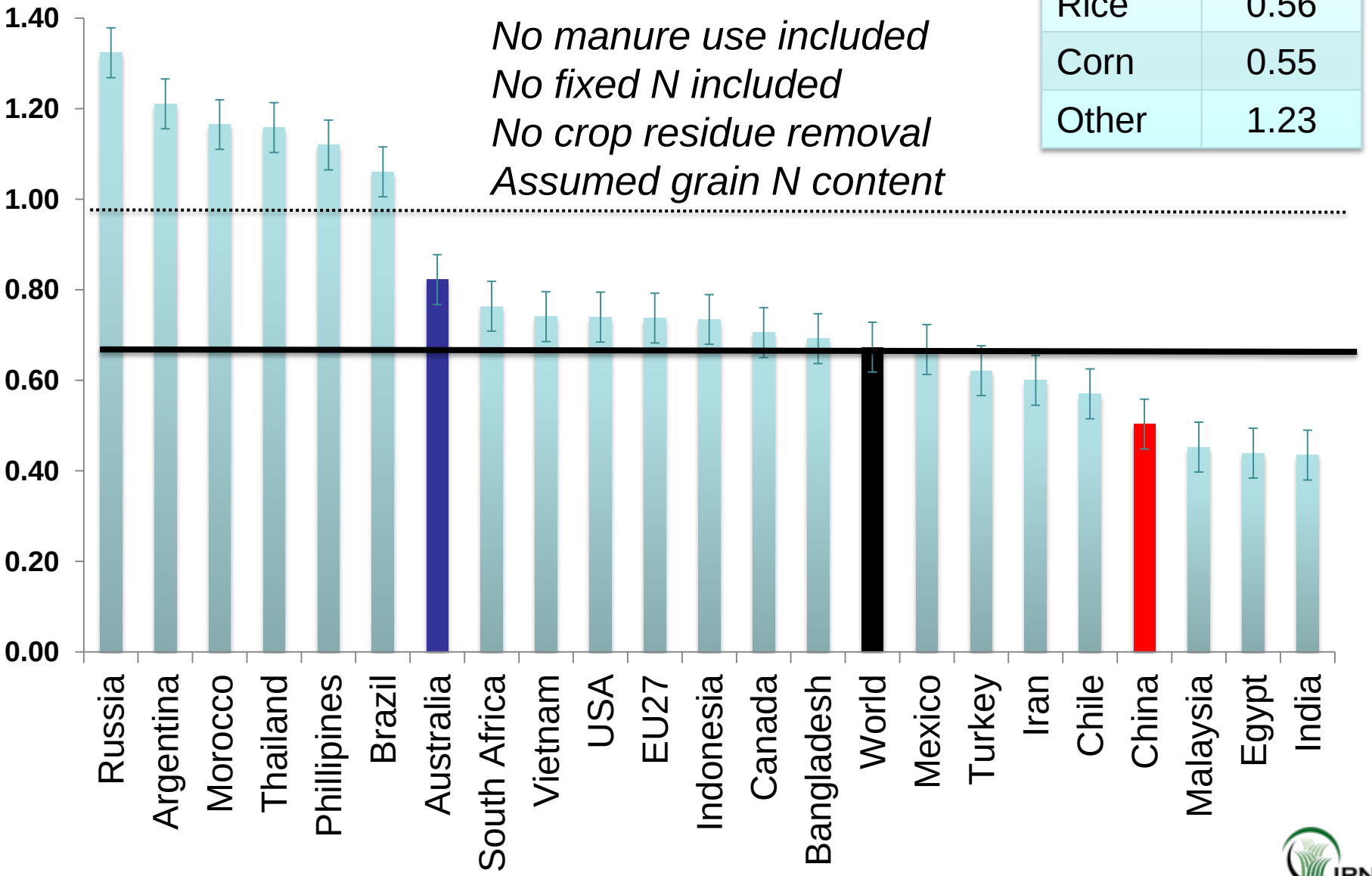
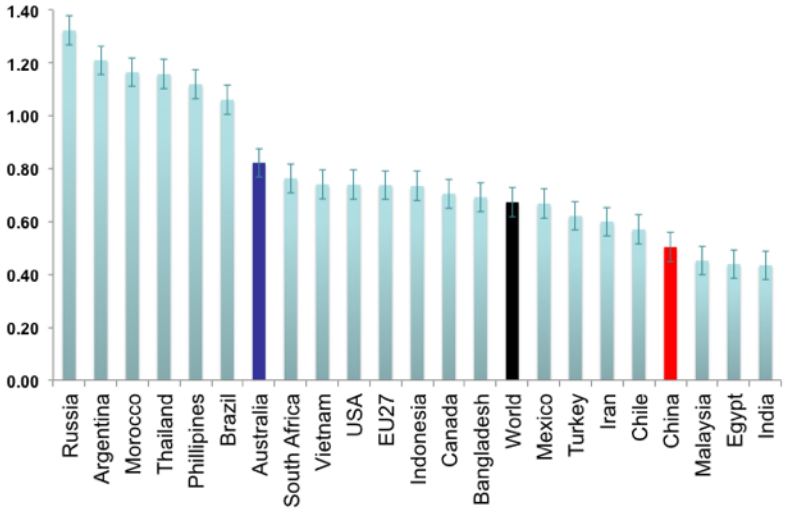
Cereal N PNB - kg N grain/kg N fertilizer

Crop	PNB
Wheat	0.74
Rice	0.56
Corn	0.55
Other	1.23

No manure use included
No fixed N included
No crop residue removal
Assumed grain N content

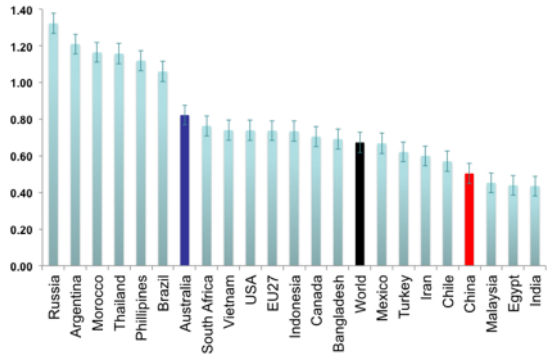


What does PNB inform?



- PNB > 1 indicates **more** nutrient is removed than applied
  - Nutrient is being mined from the soil
  - If high soil reserves, this is not problematic.
- PNB ~ 1 removal is about equal to application
- If PNB < 1 **less** nutrient is removed than applied
  - If soil reserves (eg Organic Matter) need building then a moderate excess may not be problematic..
  - The fate of nutrient is not described – *Not an environmental indicator*
    - Excess may be benign – eg as N_2 from denitrification
    - Loss may be environmentally damaging eg NO_x, NO_3^-, PM 2.5
- No estimate of scale for high or low yields/input

N surplus versus N output – scalable on productivity



Farmer Loses
Environment Loses

Farmer Wins
Environment Loses

Farmer Wins Environment Wins

NUE = 0.9

Farmer Loses
Soil Loses

Farmer Loses
Environment Loses

NUE = 1.3

Cereal Input-Output N (surplus N, kg/ha/y)

Cereal Output N (yield N, kg/ha/y)

160
120
80
40
0
-40
0
20
40
60
80
100
120
140

CHN
PAK
MYS
CHL
IND
USA
IDN
BDG
VNM
MEX
ZAF
IRN
TUR
PHL
THA
BRA
CAN
EU27
AUS
MAR
RUS
ARG

Norton et al. 2015, GPNM Tech Paper

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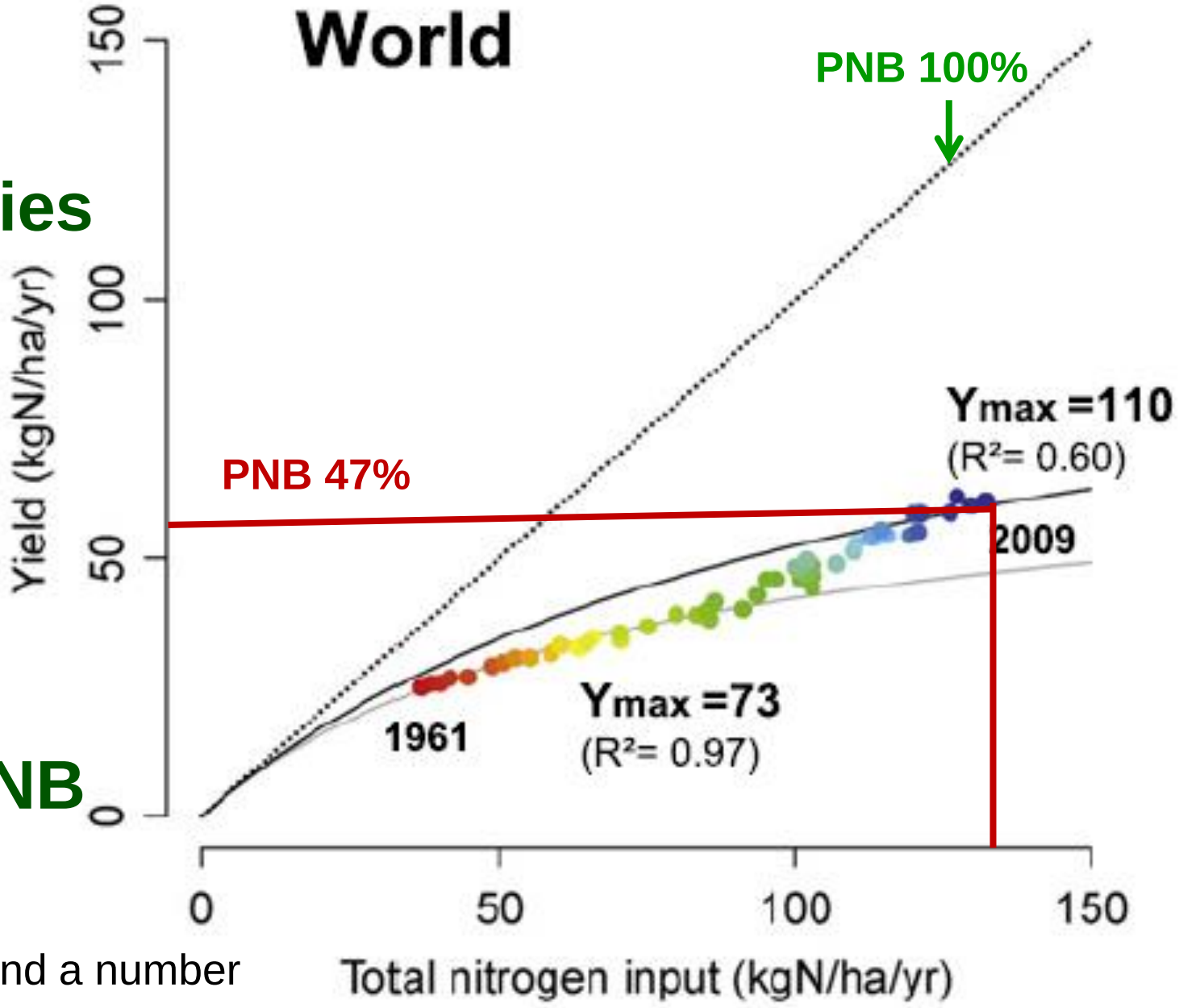
NUE trajectories over 48 years

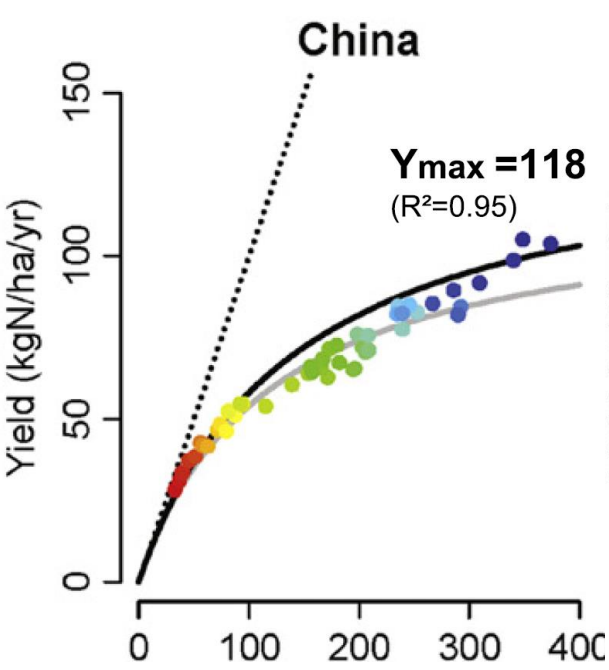
↑ yield stable PNB

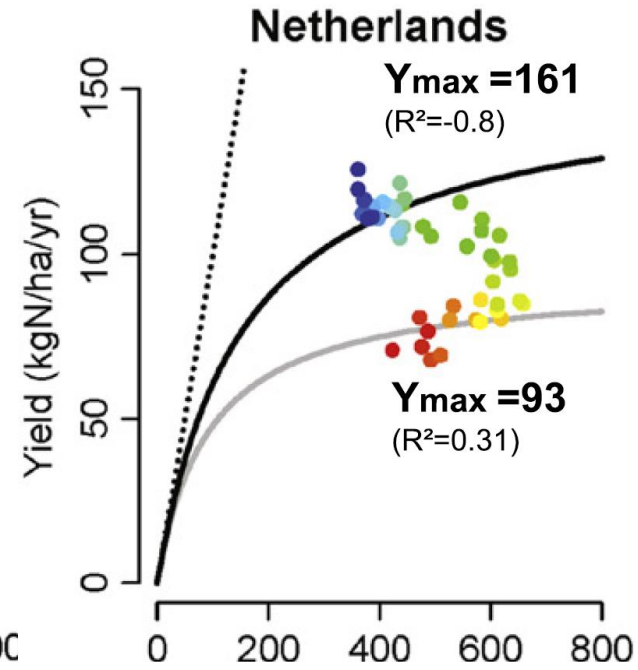


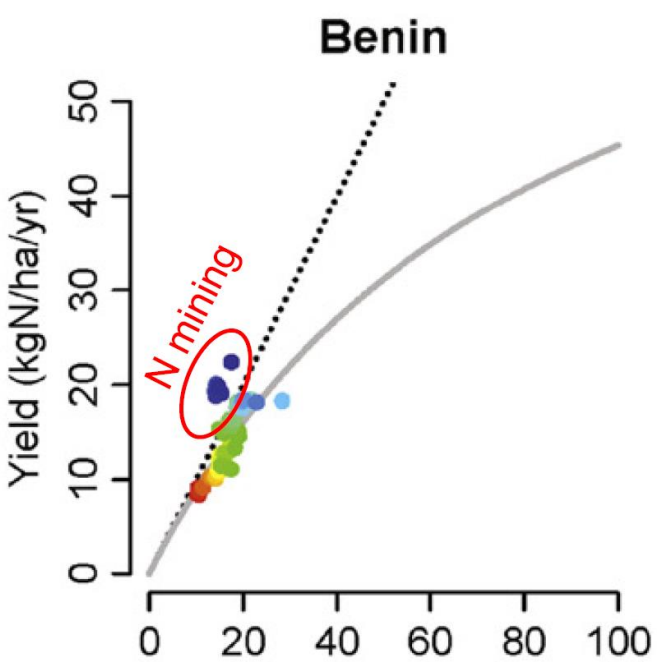
Going beyond a number

Lassaletta et al., 2014, Environ. Res. Lett. 9 (2014) 105011 (9pp)

Contrasting trajectories







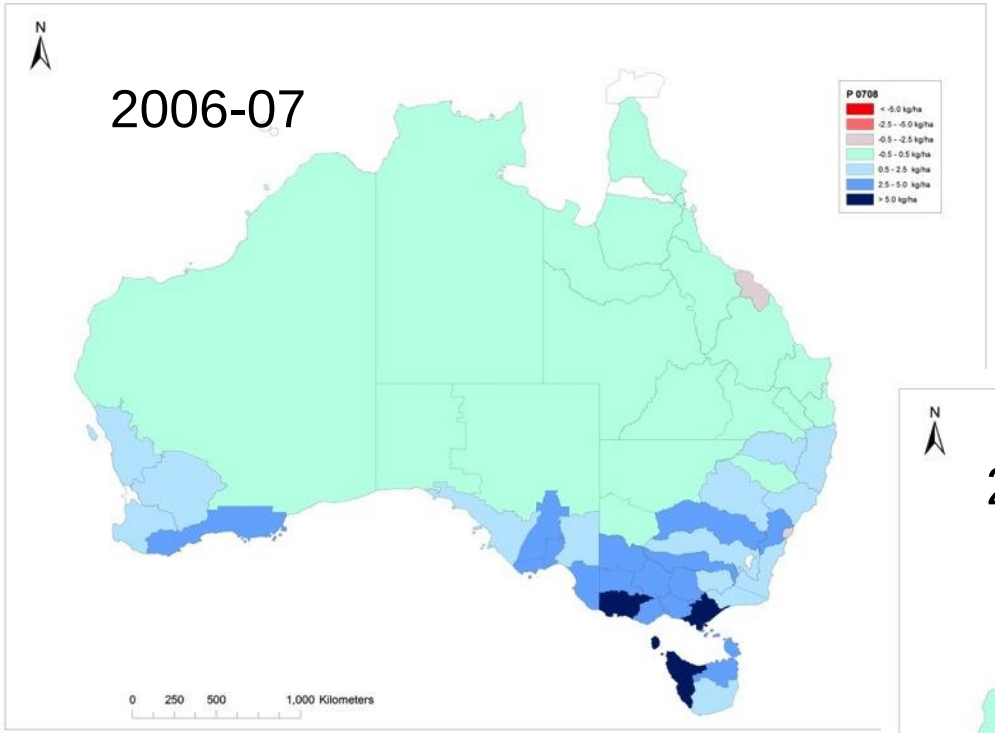
Yield high
Increase slowing
Lowering of NUE

Yield increasing
Increase high
Increase of NUE

Yield low
Increase coming
High NUE

Lassaletta et al., 2014, Environ. Res. Lett. 9 (2014) 105011 (9pp)

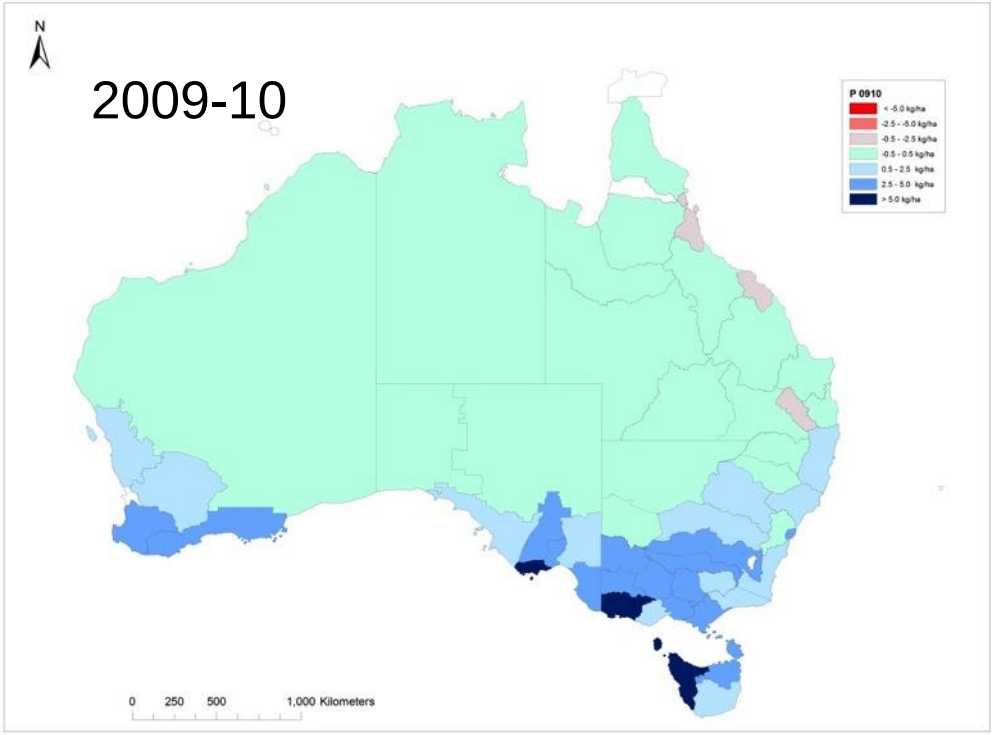
Spatially and temporally variable



(kg P (P in - P out)/ha ag land)

P balance intensity – PNB per ha of agricultural land

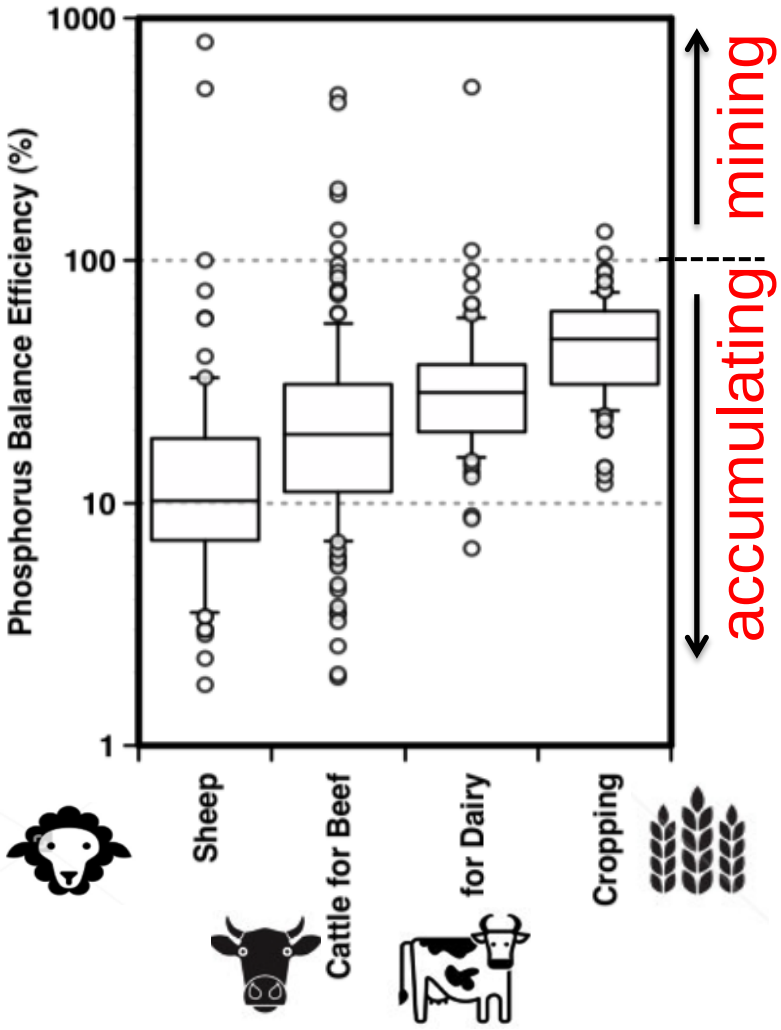
(cropped or fertilized or farmed or agricultural or total area)



- < -5.0 kg/ha
- -2.5 - -5.0 kg/ha
- -0.5 - -2.5 kg/ha
- -0.5 - 0.5 kg/ha
- 0.5 - 2.5 kg/ha
- 2.5 - 5.0 kg/ha
- > 5.0 kg/ha

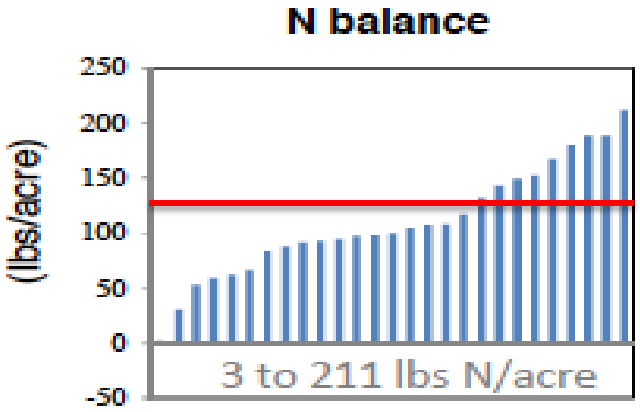
Efficiency changes among industries

– Phosphorus PNB



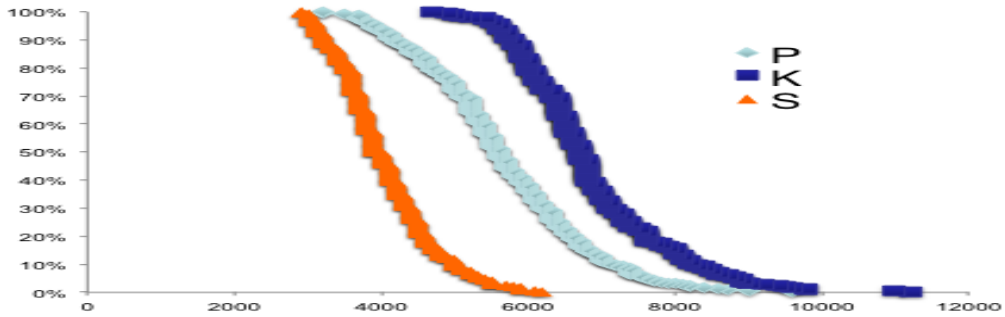
Weaver and Wong

- Cropping (48%) > Dairy (29%) > Beef (19%) > Sheep (11%)
- Large within and between industry variation
- What causes the variation in efficiency?
  - between (outputs)
  - within (management)
- The mean can stay the same but nutrient performance improves.



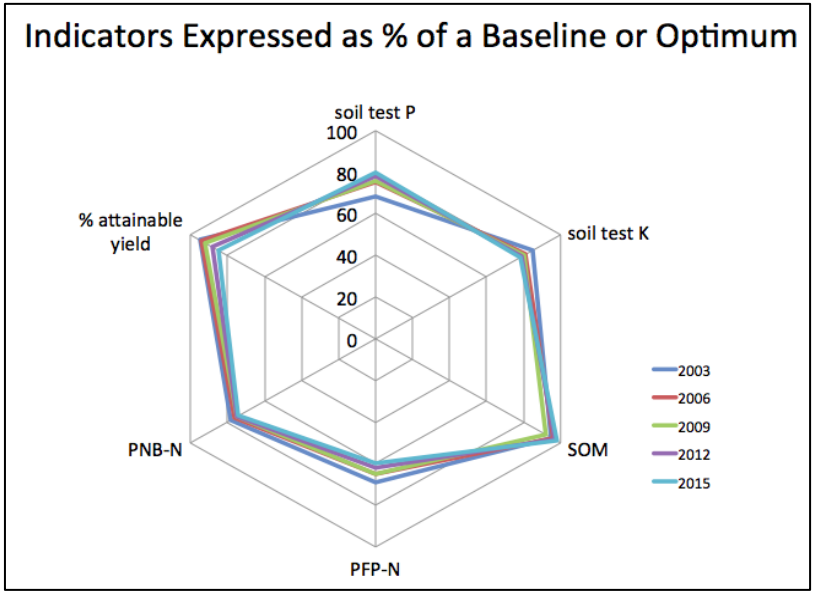
Deriving PNB/PFP/NUE
- use the best data possible

- Should look to have regional and industry specific values – purpose is to benchmark changes.
- Have good quality data on production.
- Regional & crop specific fertilizer application rates.
- Regional & crop specific product nutrient concentrations.
  - Canola
    - UEP 36 kg N/t
    - MNSA 49 kg N/t



- Include non-fertilizer nutrient inputs & removals
  - Manures, fixed N, cover crops, crop residue management

What are the lessons?

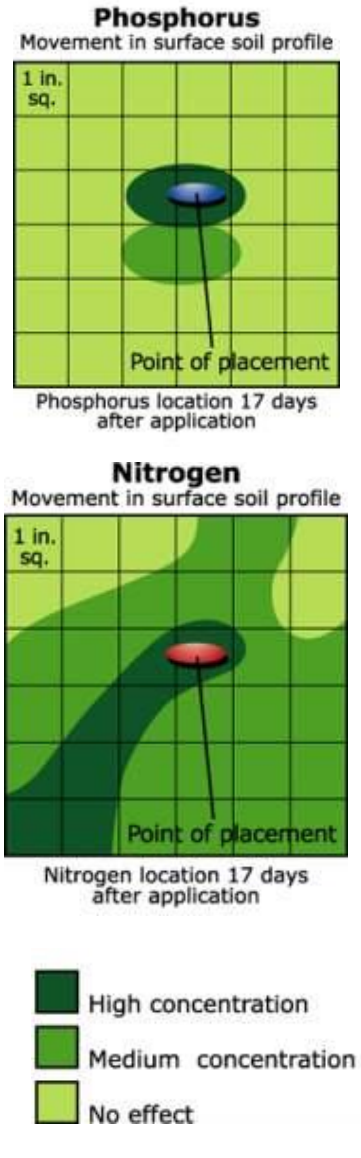


- Link nutrient performance to
  - Productivity (*eg* yield gaps)
  - Potential losses to the environment
  - Change in soil nutrient status
- No single metric can convey the complexity.
- **Involve farmers in these metrics**
  - **Farm scale assessments.**
  - **Nutrient issues are regional.**
  - **Interventions will be by farmers.**

- Not all are interested in all three sustainability goals.

Overview of improving NUE

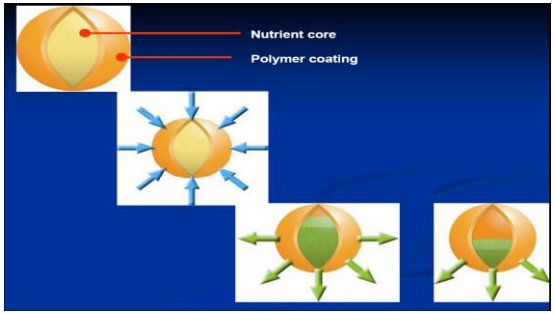
- **Build on a basis of good agronomy.**
- N and P approaches differ
  - N has more loss pathways than P
    - leaching, denitrification, or volatilization
  - Fertilizer P not removed by the crop at harvest remains in the soil (address soil erosion).
- N efficiency also has a strong environmental driver
  - N_2O production – potent GHG (~1% applied N)
    - ~23% N_2O & ~5% of total GHG emissions*
  - Nitrate leaching
  - Ammonia particulates and re-deposition
- *Recycling of organics in-field or through the supply chain.*



*2005 – World Resources Institute

Developing the 4R approach

- NUE improves when losses are minimized
- Right source – enhanced efficiency fertilizers
  - Slow release products (e.g. IBDU/low solubility)
  - Controlled release products (e.g. coated)
  - Stabilized materials (e.g. nitrification/urease inhibitors)
  - Chemical protectants (e.g. resist fixation/precipitation)
  - Adjuvants to assist with accessing soil reserves (microbes)
- Need for evidence of efficacy – well designed field experiments -



Developing the 4R approach

- NUE improve when losses are minimized
- Right rate and time to match demand of the crop

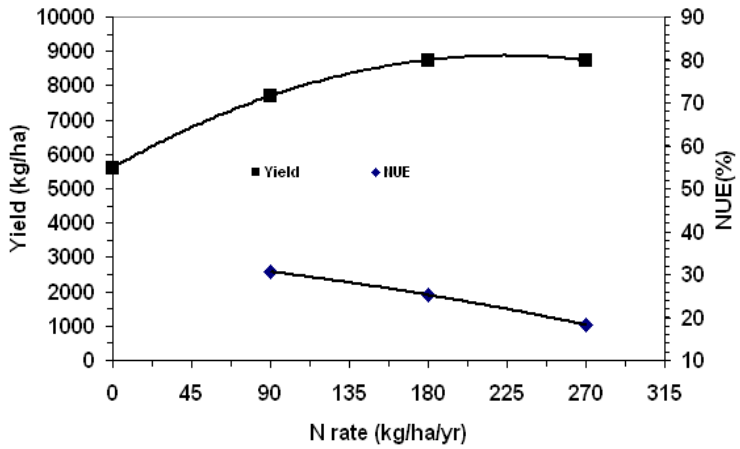
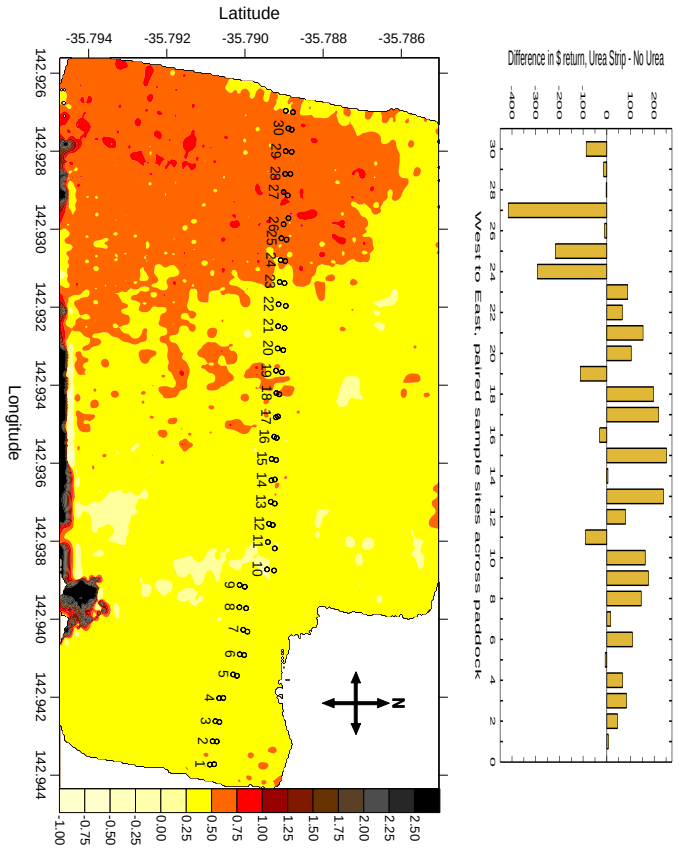


Figure 5. Balanced median N_2O emission rates as a function of applied N (adapted from Bouwman, Boumans, and Batjes, 2002).

- Lowering rates to the plateau of the yield response curve has little effect on yield, but a large effect on NUE, and a large environmental GHG impact
- Raising rates to ensure the crop in not nutrient limited.
- Timed to match crop demand
  - Split applications
  - Controlled release products
  - Banding

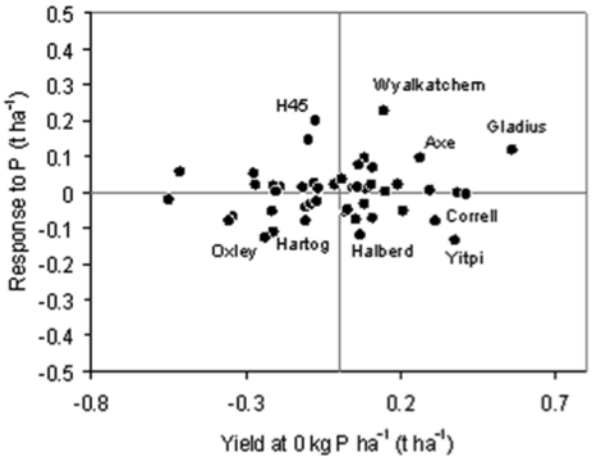
Developing the 4R approach

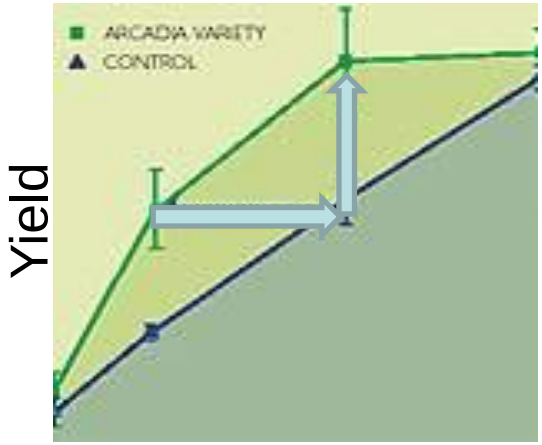
- NUE improve when losses are minimized
- Right place to match the spatial pattern of crop demand and to protect sensitive areas.
- Use of variable rate applicators in response to crop or soil sensing.
  - EM38 (subsoil limitations)
  - Remote (satellite, aircraft), mid-range (drones) or proximal (machine/hand held) crop sensors.
  - Leaf colour charts



Role of genetics in improving NUE

- Is there genetic variability for these traits
  - Selection under low or high nutrient
  - Why does this occur?
- Increase access to N & P
  - Root morphology/distribution
  - Root exudates (solubilize P)
- Increase physiological use efficiency
  - Higher remobilization of P and N to product
  - Alternative storage compounds
    - e.g. alanine amino transferase overexpression
- Symbiotic/non-symbiotic N associations



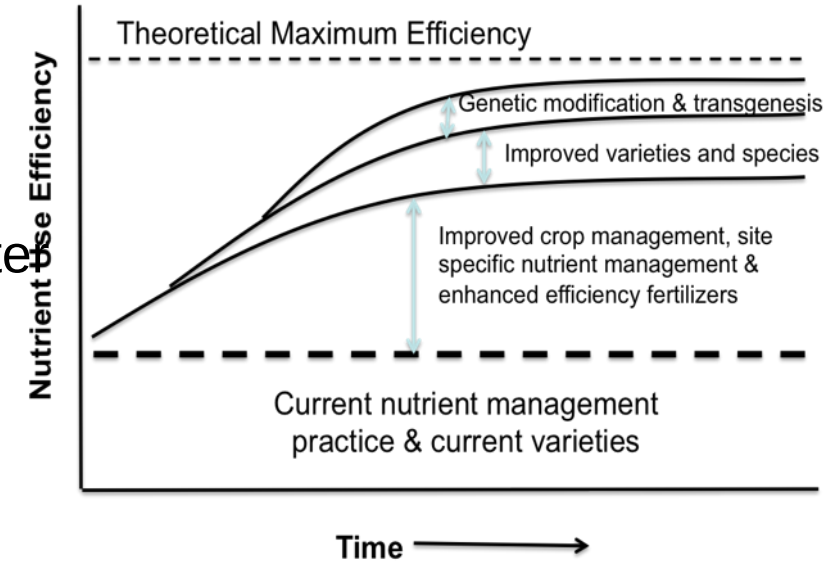


Good et al. 2007. Can.J.Bot.

The nutrient has to come from somewhere.

Summary

- PNB and PFB are useful broad scale metrics
  - Neither are productivity or environmental indicators.
  - Need transparent definitions (system, time, data sources)
  - Need to be linked to other indicators such as soil health or water/air quality.
- There are many strategies for improving PNB & PFP
  - Many can be adopted now to better match crop demand and soil/fertilizer nutrient supply.
  - None alone will provide the 'solution' alone.



- Engagement with farmers is a critical aspect of improving NUE.

Thanks for your attention…

http://www.ini2016.com

Papers close April 28; Early registration close August 26; Partnership opportunities