

# Global Potential for Adaptively Managing Nitrogen Using Active Sensors

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# Are Sensors Relevant in Developing-World Agriculture?



# Are Sensors Relevant in Developing-World Agriculture?

**Cook et al., 2003**

“We question this assertion and postulate that the basic purpose of precision agriculture – to provide spatial information to reduce uncertainty – far from being a luxury, and could be viewed as essential to accelerate change in the developing world...”

“The need for [site-specific] information is actually greater [in the developing world], principally because of stronger imperative for change and lack of conventional support.”

# The Nutrient Expert decision support tool

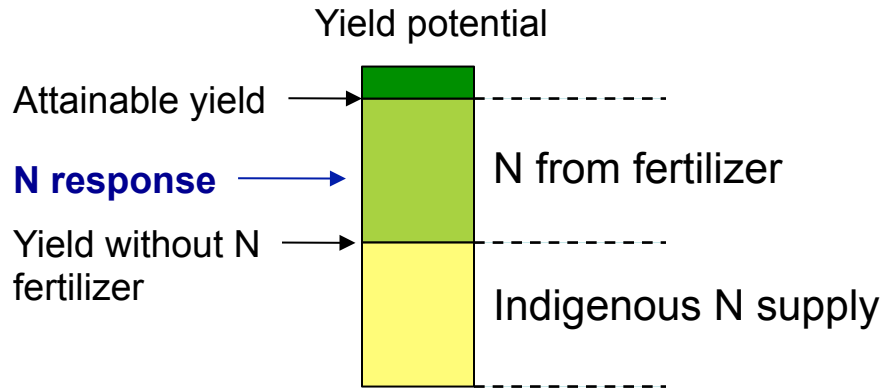
- Nutrient Expert is a computer-based decision support tool for crop advisers. It uses the principles of site-specific nutrient management (SSNM).
- SSNM aims to supply a crop's nutrient requirements tailored to a specific field or growing environment.
  - accounts for **indigenous nutrient sources**
  - applies fertilizer at **optimal rates** and at **critical growth stages** → 4Rs (right source, right rate, right time, right place)

The image displays three screenshots of the Nutrient Expert decision support tool interface, each showing a different crop-specific version.

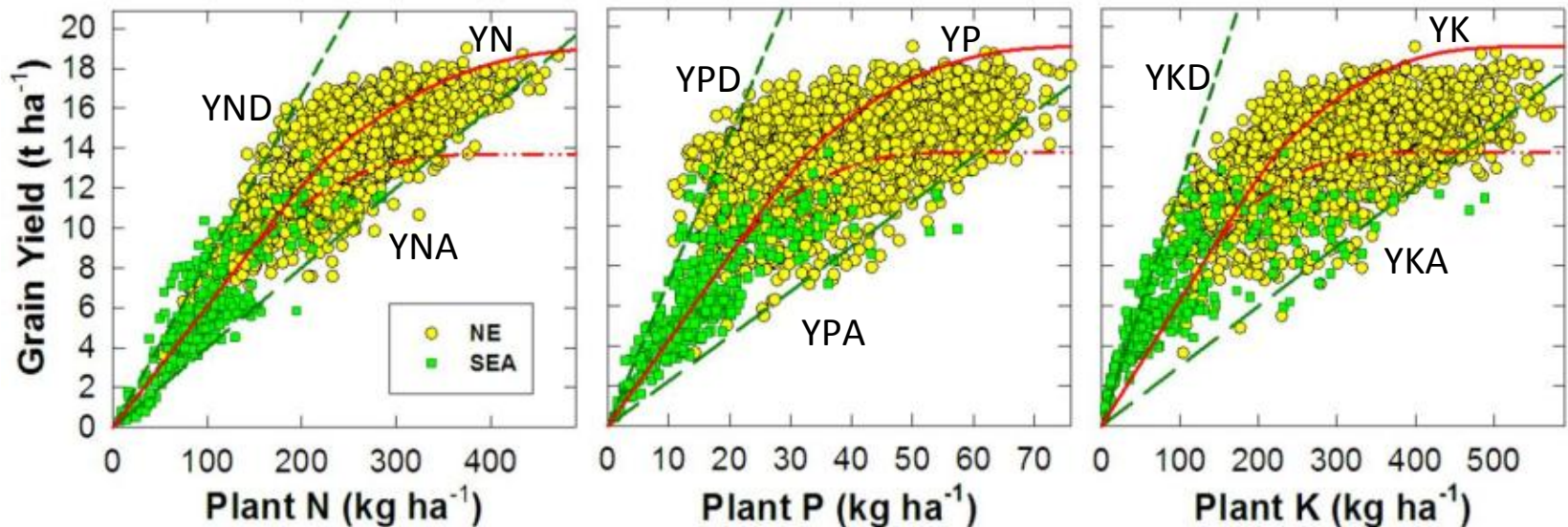
- Nutrient Expert<sup>®</sup> for Hybrid Maize** (Southeast Asia, Version 1.11, June 2012):
  - Header: Nutrient Expert<sup>®</sup> for Hybrid Maize
  - Text: First time user? Working in a new location? Make sure to have the 'Settings' right!
  - Section: Nutrient Expert for Hybrid Maize helps you to:
    - develop an optimal planting density for your location
    - evaluate current nutrient management practices
    - determine a meaningful yield goal based on attainable yield
    - estimate fertilizer NPK rates required for the selected yield goal
    - translate fertilizer NPK rates into fertilizer sources
    - develop an application strategy for fertilizers (right source, right rate, right time, and right place)
    - compare the expected or actual benefit of current and improved practices.
  - Text: To start, click a button
  - Flowchart: Current NPK Practice → Planting Density → SSNM Rates → Sources & Splitting
- 玉米养分专家 (中国)** (China, Version 1.0, August 2012):
  - Header: 玉米养分专家 (中国)
  - Text: 是否是首次使用者? 是否在该地区首次使用? 请确认“设置”正确!
  - Section: 玉米养分专家可以帮助你:
    - 推荐适宜本地的最佳种植密度
    - 评估当前养分管理措施
    - 在可获得的生产基础上确定有意义的目标产量
    - 预估一定目标产量下所需养分用量
    - 将所需养分换算为肥料用量
    - 制定合理的肥料施用策略 (合适的用量, 合适的肥料种类, 合适的施用位置, 合适的施用时期), 以及
    - 比较当前优化措施与改进措施的实际经济效益
  - Text: 开始, 请点击按钮
  - Flowchart: 当前养分管理措施/目标产量 → 种植密度 → 养分优化量/施肥量 → 肥料种类及/分次施用 → 经济效益分析
- Nutrient Expert<sup>™</sup> for Wheat** (South Asia, Version 1.0, March 2012):
  - Header: Nutrient Expert<sup>™</sup> for Wheat
  - Text: First time user? Working in a new location? Make sure to have the 'Settings' right!
  - Section: Nutrient Expert for Wheat is a decision support tool for developing farmer-specific fertilizer recommendations. It helps you to:
    - evaluate current nutrient management practices
    - determine a meaningful yield goal based on attainable yield
    - estimate fertilizer NPK rates required for the selected yield goal
    - translate fertilizer NPK rates into fertilizer sources
    - develop an application strategy for fertilizers (right source, right rate, right time, right place), and
    - compare the expected or actual benefit of current and improved practices.
  - Text: To start, click a button
  - Flowchart: Current FFP & Yield → SSNM Rates → Sources & Splitting → Profit Analysis

# Estimating fertilizer requirement

- Estimate attainable yield
- Determine yield response to fertilizer application



- Estimate nutrient uptake requirement from the relationship between grain yield and balanced uptake of nutrients at harvest



# Nutrient Expert is developed through collaboration with local experts and stakeholders

- Collaboration with target users and stakeholders through consultation meetings
  - Collection of locally-available agronomic data and information
  - Field testing, evaluation, and refinement of the software
  - Building confidence in the concept with collaborators



## Nutrient Expert recommendation:

- Tailored to location-specific conditions
- Consistent with 4Rs:
  - right source
  - right rate
  - right time
  - right place
- Option to tailor recommendation based on farmer's resource availability

Nutrient Expert for Hybrid Maize

[Home](#)
[Settings](#)
[Help](#)

Current NM Practice
Planting Density
SSNM Rates
Sources and Splitting
Profit Analysis

**Name and/or location:**  **Field size:**  ha

Fertilizer N, P, and K requirements are based on yield goal (i.e. attainable yield) and expected yield responses to fertilizer application.

1. What is the attainable yield for your location?  t/ha
2. What do you do with maize residues after harvest?
 

Remove all the above ground residues from the field  
 Retain stover in the field and incorporate  
 Retain stover in the field and bur

Compost stover for incorporation to next crop  
 Retain 50% of stover on the surface  
 Retain 100% of stover on the surface
3. Will you apply organic fertilizers (e.g. manure)?  Yes  No
4. Determine residual benefit from your previous crop?  Yes  No
5. Do you have results from omission plot trials conducted in a similar field in your municipality or district?   Yes  No  
 N response:  t/ha      P response:  t/ha      K response:  t/ha
6. Is your soil known to be of volcanic origin and contain allophane?  Yes  No
7. Account for nutrient credits?  Yes  No

N response (t/ha)	Fertilizer N (kg/ha)
2	110
3	130
4	150
5	170
6	190
7	210
8	230

Yield (t/ha)	P response (t/ha)	Fertilizer P <sub>2</sub> O <sub>5</sub> (kg/ha)
0		
0.5		
1.0		
1.5		
2.0		
2.5		

Yield (t/ha)	K response (t/ha)	Fertilizer K <sub>2</sub> O (kg/ha)
0		
0.5		
1.0		
1.5		
2.0		
2.5		

N credits:  kg N/ha

Final N rate:  kg N/ha

Final P rate:  kg P<sub>2</sub>O<sub>5</sub>/ha

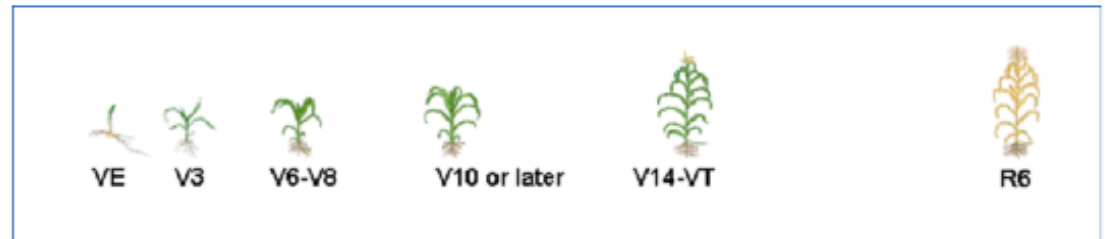
Final K rate:  kg K<sub>2</sub>O/ha

# Nutrient Expert for Hybrid Maize

**Name and/or location** 
**Growing season** 
**Field size:**  ha  
**Current yield**  ton (18% MC)  t/ha (15.5% MC)
 **Growing environment**

**Recommended alternative practice for hybrid mai**  
**Yield goal:**  ton (18% MC)  t/ha (15.5% MC)

**Planting density:**  plants/ha
 **Distance between rows:**  cm
 **Distance between plants:**  cm



Right rate

Growth stage	Days after	Soil moisture	Fertilizer sources	Weight of full bag (kg)	Amount t
Basal	0	sufficient	Urea	50	2
			Single Super Phosphate	50	3.5
			Muriate of Potash	50	1
V6	25-30	sufficient	Urea	50	2.5
V10	35-40	sufficient	Urea	50	2

**Other sources of nutrients**

Crop residue (rice):   
 Organic fertilizer:  t  
 N:  kg  
 P<sub>2</sub>O<sub>5</sub>:  kg  
 K<sub>2</sub>O:  kg

Right time

Fertilizer rates are adjusted to field size

Deficient Nutrient	Recommendation to correct deficiency
Sulfur	Apply 30-60 kg/ha elemental sulfur or 227-375 kg/ha gypsum as basal.
Zinc	Apply 25-30 kg/ha zinc sulfate as basal.

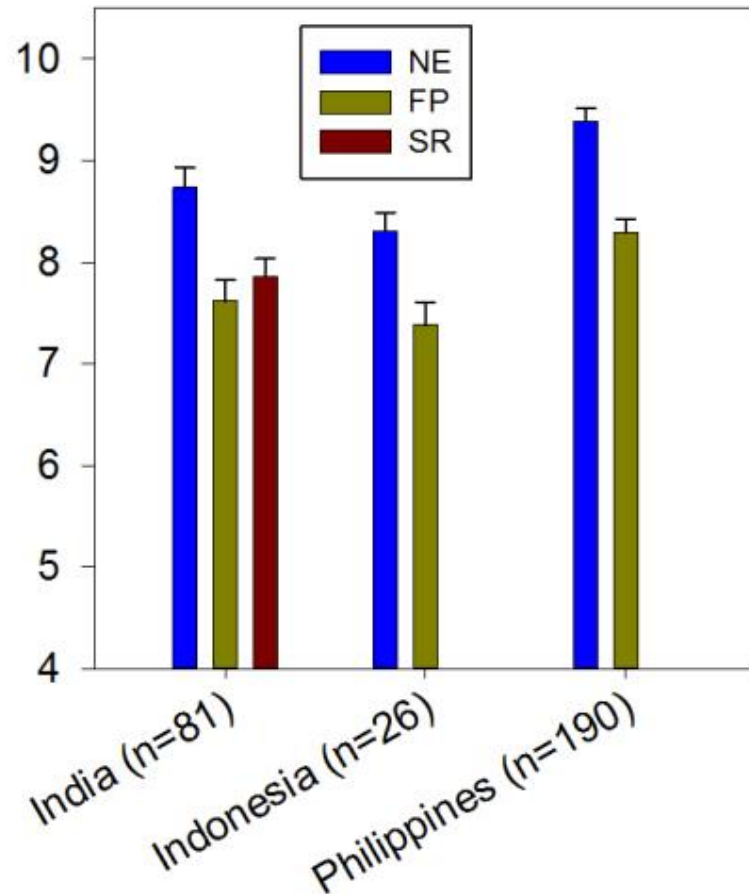
Right source



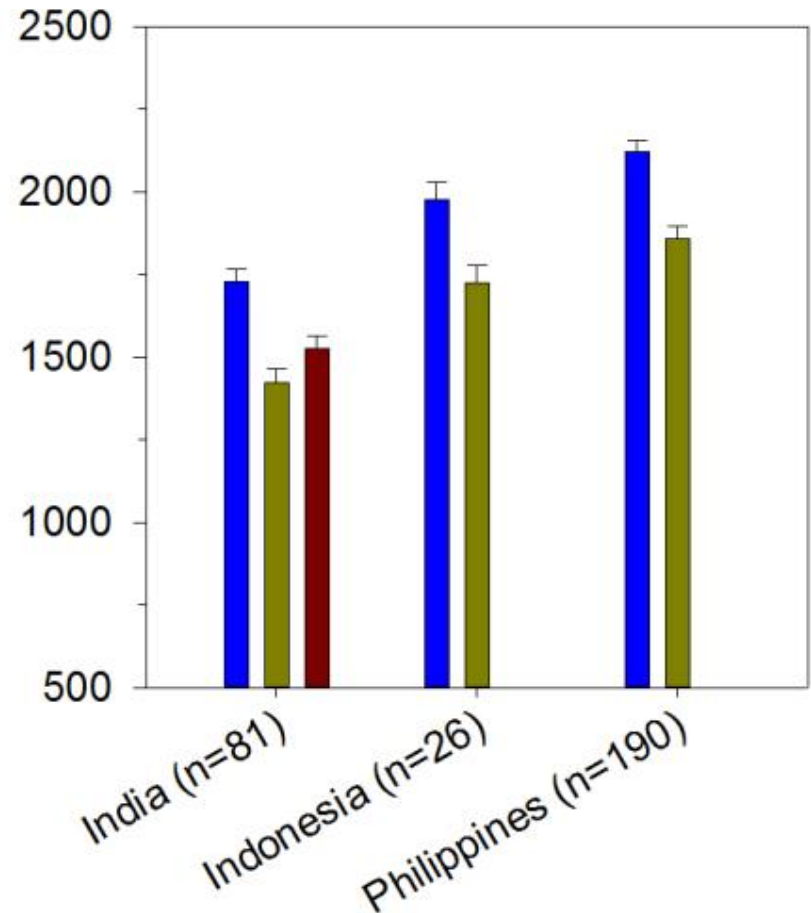
# Field validation results of Nutrient Expert for maize

India, Indonesia, Philippines (2010-2013):  
Farmers' current yield level < attainable yield

Grain yield (t/ha)



GRF (USD/ha)



GRF = gross returns above seed and fertilizer costs

# NE for maize performance across 22 sites in Indonesia

Parameter	Unit	FFP	NE	Difference (NE – FFP)
Grain yield	t/ha	7.51	8.40	<b>0.89 ***</b>
Fertilizer N	kg/ha	173	160	-12.30 ns
Fertilizer P <sub>2</sub> O <sub>5</sub>	kg/ha	43	33	-10.04 *
Fertilizer K <sub>2</sub> O	kg/ha	28	41	13.15 **
Fertilizer cost	USD/ha	126	126	0.08 ns
Gross return above seed & fertilizer	USD/ha	1761	2032	<b>270.94 ***</b>

\*\*\*, \*\*, \*: significant at <0.001, 0.01, and 0.05 level; ns = not significant

Data from 22 farmers' fields in five locations under irrigated (rice-rice-maize) and favorable rainfed (maize-maize) environments, 2010-2011

Seed cost: USD 5.08/kg; Price of maize grain: USD 0.27/kg; Price of fertilizer: actual local prices; USD 1 = IDR 8850

# NE for maize performance across 24 sites in the Philippines

Parameter	Unit	FFP	NE	Difference (NE – FFP)
Grain yield	t/ha	7.49	9.16	<b>1.67 ***</b>
Fertilizer N	kg/ha	114	132	18 ns
Fertilizer P <sub>2</sub> O <sub>5</sub>	kg/ha	26	36	10 ***
Fertilizer K <sub>2</sub> O	kg/ha	18	35	17 ***
Fertilizer cost	USD/ha	176	241	65 ***
Gross return above seed & fertilizer	USD/ha	1730	2126	<b>395 ***</b>

\*\*\*, \*\*, \*: significant at <0.001, 0.01, and 0.05 level; ns = not significant

Data from 24 farmers' fields in six regions under favorable rainfed (maize-maize, rice-maize) environments, dry season 2010-2011

Price of seeds, fertilizer, and maize grain are based on actual local prices; USD 1 = Php 43

# FFP vs SSNM (NE) in Iloilo, Philippines



# NE for maize performance across 27 sites in India

Andhra Pradesh (n = 27)

Parameter	Unit	FP	NE	NE – FP	
Grain yield	kg/ha	8568	9699	<b>1131</b>	***
Fertilizer N	kg/ha	288	203	-85	**
Fertilizer P <sub>2</sub> O <sub>5</sub>	kg/ha	153	54	-99	***
Fertilizer K <sub>2</sub> O	kg/ha	68	74	6	ns
Fertilizer cost	INR/ha	9509	5459	-4050	**
GRF <sup>1</sup>	INR/ha	76167	91770	<b>15603</b>	***

\*\*\*, \*\*, \*: significant at <0.001, 0.01, and 0.05 level; ns = not significant

<sup>1</sup> GRF = gross return above fertilizer cost

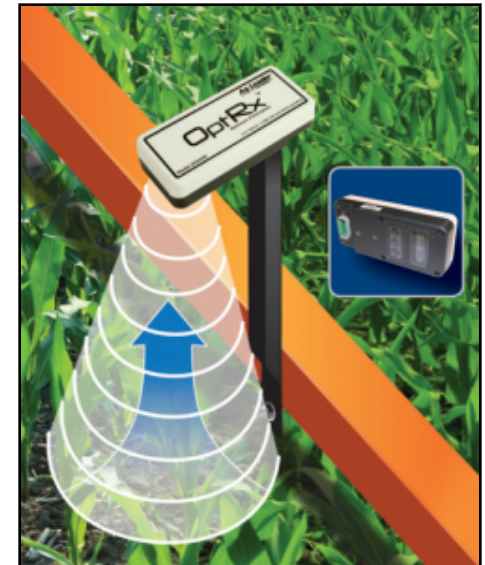
Prices (in INR/kg): maize = 10.00; N = 11.40; P<sub>2</sub>O<sub>5</sub> = 32.20; K<sub>2</sub>O = 18.80

# Field validation results of Nutrient Expert for maize in China (2010-2012)

Year	Treatment	n	Grain yield (t/ha)	Fertilizer rate (kg/ha)		
				N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
2010	FP	138	8.6	225	53	40
	Soil test	127	8.8	195	47	69
	<b>NE</b>	<b>138</b>	<b>8.7</b>	<b>138</b>	<b>50</b>	<b>63</b>
2011	FP	185	10.0	222	64	44
	Soil test	90	10.5	215	65	86
	<b>NE</b>	<b>185</b>	<b>10.6</b>	<b>161</b>	<b>49</b>	<b>61</b>
2012	FP	138	10.6	235	67	59
	Soil test	109	11.1	204	60	72
	<b>NE</b>	<b>138</b>	<b>10.9</b>	<b>167</b>	<b>63</b>	<b>74</b>

# Estimating fertilizer requirement for Nutrient Expert

- Estimate attainable yield
- Determine yield response to fertilizer application
- Estimate nutrient uptake requirement
- Estimate site-specific nutrient use efficiency




# Developing a Sensor-Based Program

- 1. Calibration
- 2. Validation
- 3. Development
- 4. Training

### Sensor Based N Rate Calculator, Rice 2009

DATA ENTRY	
Max yield, bu/ac	320
Planting Date	23-Apr-09
Sensing Date	29-Jun-09
NDVI, N Rich Strip	0.78
NDVI, Farmer's practice	0.767
NUE expected	0.5



RESULTS	
Response Index	1.19
Days, planting to sensing	66
Potential yield (0-N), bu/ac	223
Potential yield (+ N), bu/ac	266
Fertilizer N, lb N/ac	46

**Note:**

NRS (Nitrogen Rich Strip) - Reference Strip	Max yield set to 2 times the average yield in the area
FP (Farmer's Practice)	Plough rice: 45 lbs/BU
NDVI (normalized difference vegetation index)	Rice grain N = 1.2%

**PROCEDURE:**

1. Farmer is asked to Establish the Maximum Yield Achievable, For that Year (YPMAX)
2. Sense the N Rich Strip (NRS)
3. Sense a strip parallel to the NRS (Farmer's Practice or FP)
4. Determine how many days from planting to sensing
5. Compute INSEY (NDVI/days from planting to sensing)
6. Predict yield
7. Predict grain N uptake in FP
8. Predict grain N uptake in FP based on R1
9. N rate = (grain N uptake in FP based on R1 - grain N uptake in FP)/expected NUE

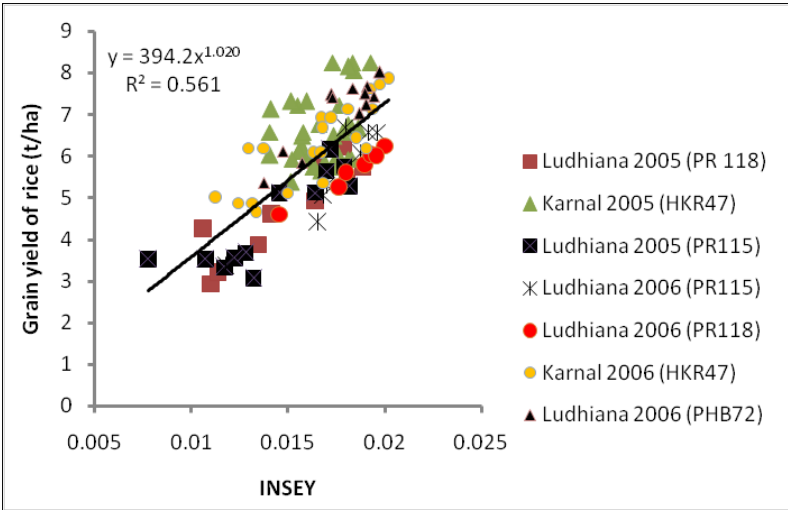
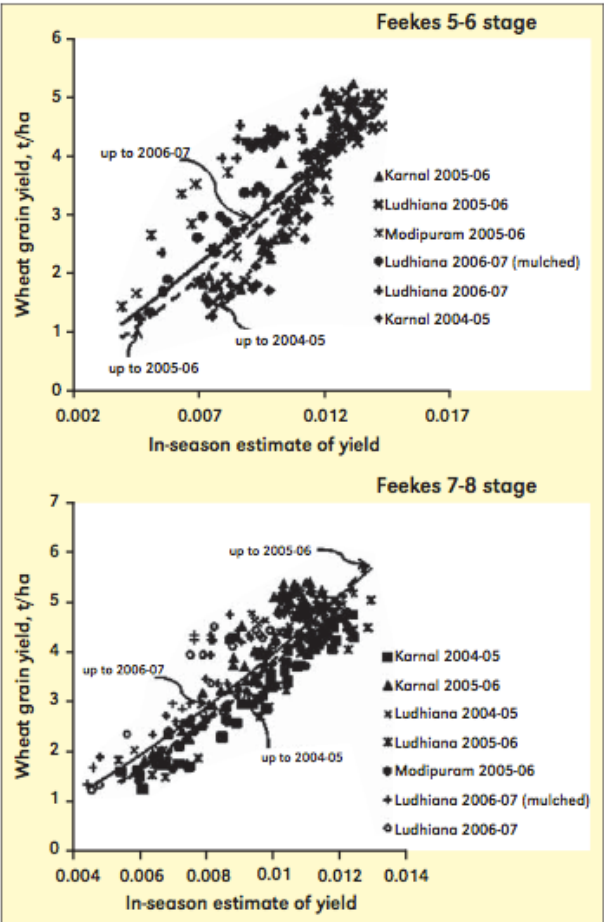
*Contributors: Brenda Tubana, Dustin Harrell, and Timothy Walker*





# Calibration

- Establish sensor-based model for predicting grain yield potential



# Validation

- Evaluate the performance of sensor-based N decision tool against the commonly applied flat N rate



## N management in rice: application of GreenSeeker optical sensor-guided fertilizer in India

Fertilizer N application (kg N/ha)				Grain yield (t/ha)			
Basal	21DAT	42 DAT (GS guided)*	Total	2006 PR118	2007 PR118	2008 PAU201	2008 PHB71
0	0	0	0	3.85	4.05	4.16	3.42
40	40	40	120	6.19	5.01	6.86	6.16
30	30	32	92	5.63			
30	30	23	83		4.74		
30	30	48	108			6.59	
30	30	49	109				6.09
L.S.D. (p=0.05)				0.774	0.337	0.488	0.488

# Sensor Calibration and Validation Research

- Li et al., 2009
  - Bijay-Singh et al., 2011
  - Cao et al., 2012
- Wheat**
- Yao et al., 2012
  - Xue et al., 2013
- Rice**



# Development and Training



## Sensor Based Nitrogen Rate Calculator

Argentina  
Australia  
Canada  
China  
India  
Mexico  
Pakistan  
Philippines  
Turkey  
USA  
Uzbekistan

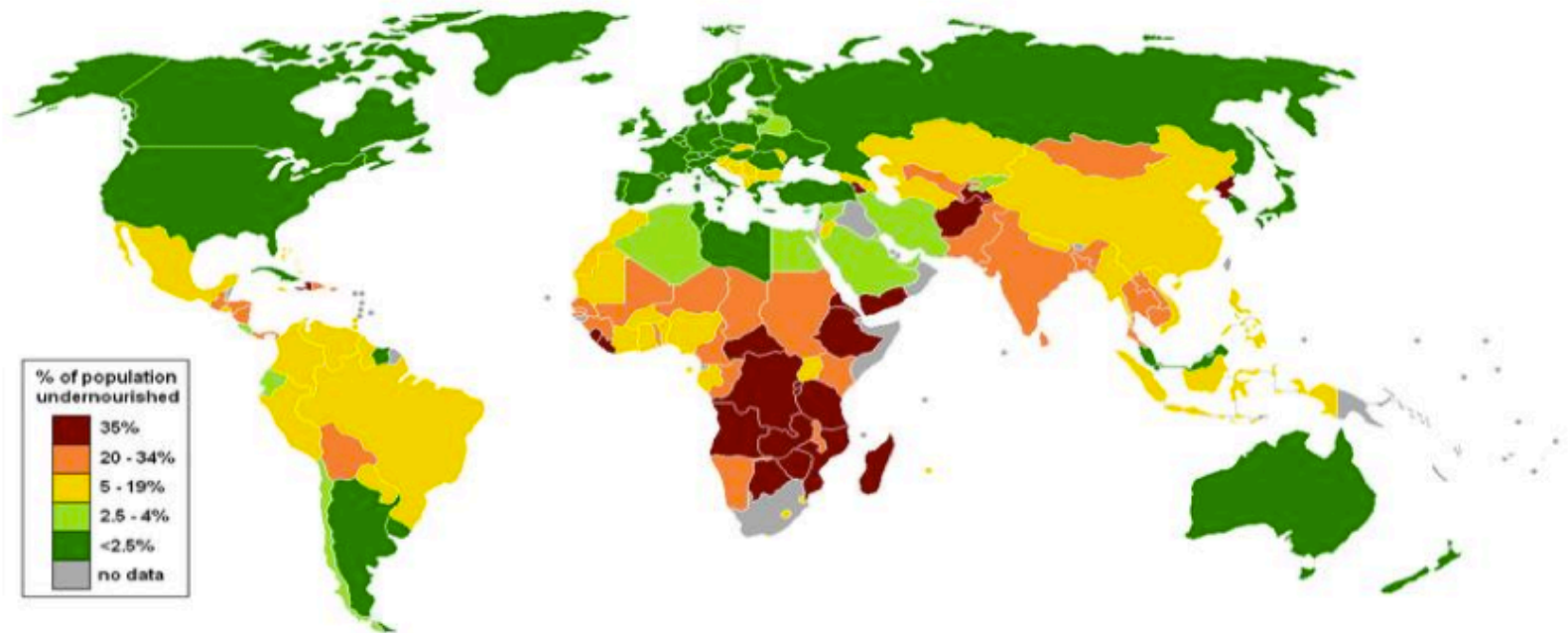
Topdress and Sidedress N Rates for Corn and Wheat

A hand holding a sensor device over a corn cob, with a calculator in the foreground.

# Challenges and Opportunities

- Cost / Profit potential
  - Handheld sensors
- Delivery mechanism for rate recommendations
  - Mobile device technology
- Continued research / extension support
  - Incomplete follow-through
- Technical support
  - Equipment operation, data collection, rate calculation
- Can be incorporated into existing SSNM strategies
- Logistics in small-holder system
  - Ownership of equipment
  - Reference strips

# Global Population and Food Security



- Population increases are placing greater pressure on the food security of certain regions of the world
- Potential food security challenges are going to affect all world residents, regardless of their location.

***Application of precision agriculture technologies will be essential for sustainable access to food for a global population***

***Global food security will be dependent on how well we adapt the principles of precision agriculture for the small holder systems of Asia***



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