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Crop, Soil, and Fertilizer Nitrogen Management Strategies to Reduce Nitrate Accumulation in Plants and Improve Nitrogen Use Efficiency

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International Nitrogen Conference, December 3-7, 2010, New Delhi

INTRODUCTION

- Nitrogen deficiency is universal, and applying fertilizer N is considered as a reasonable insurance against crop yield losses and their economic consequences.
- However, when input of N exceeds its demand, plants are no longer able to absorb excess N, which then builds up in the soil, mostly as nitrates.
- This build up not only causes imbalance of nutrients in the soil but also increases the nitrate level in groundwater supplies (NAAS 2005), ultimately impacting the nitrate content of plants.

Poor N recovery and NO_3 accumulation

	Fertiliser N recovery (AE_N)
Bijireigo et al., 1979	35%
Olson 1980	24-26%
Kitur et al., 1984	23-45%
Meisinger et al., 1985	14-65%
Sanchez and Blackmer (1988)	15-33%
Reddy and Reddy, 1993	45-59%
Raun and Johnson, 1999	33%
Dobermann, 2000	30%

35-86% unrecovered fertilizer N increases the potential for NO_3 build up in soil and further in plants

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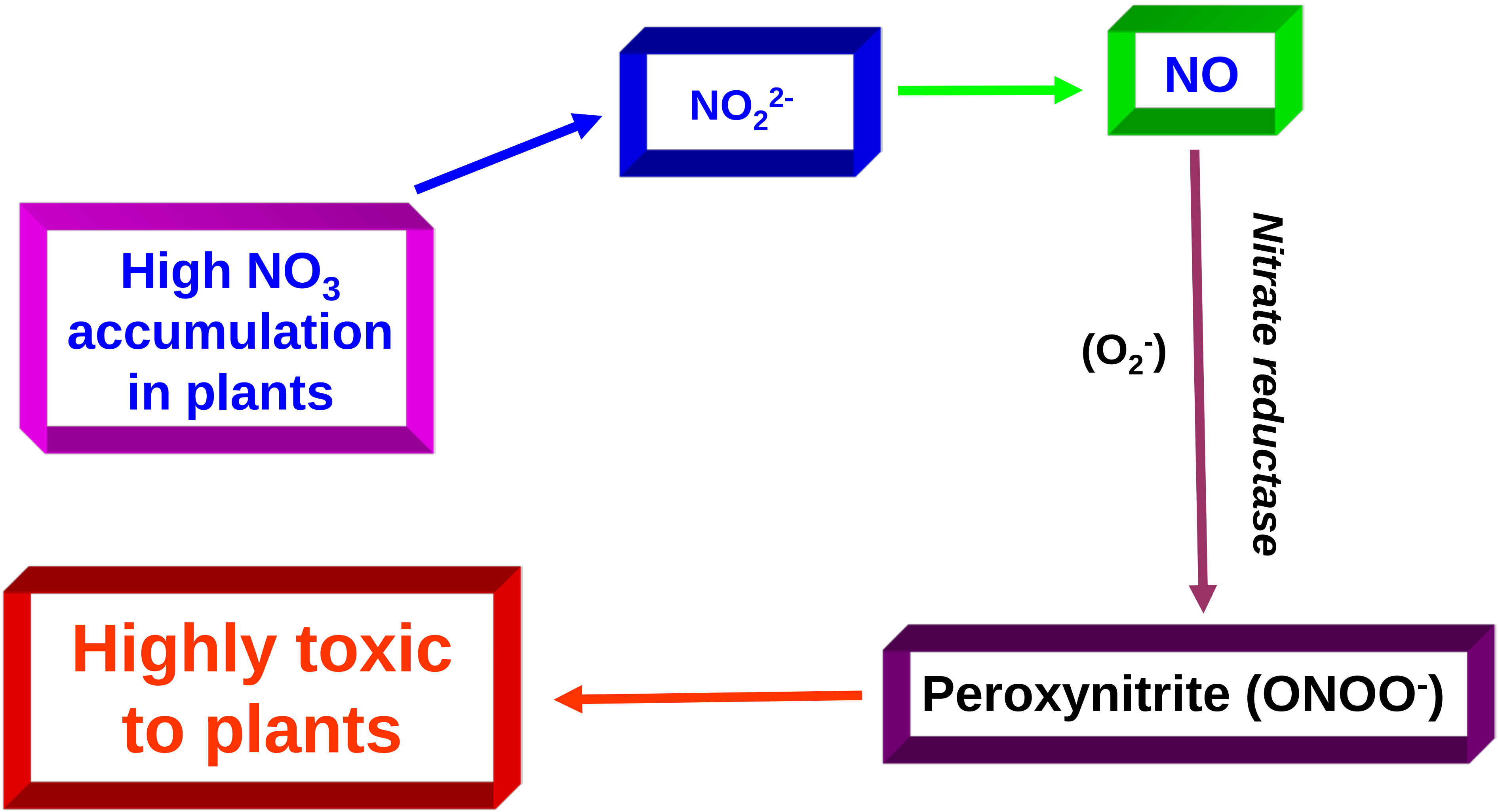
Nitrate accumulation in plants



(Anjana *et al*. 2007)

NO_3 accumulation……

- In animals, nitrite is absorbed into the bloodstream
  - binds with hemoglobin (creating methemoglobin)
  - prevents oxygen transfer (Hancock 2007)

- In humans, nitrite reacts with amines and amides to produce nitrosamines and nitrosamides
  - carcinogenic properties
  - like in animals, the production of methemoglobin impairs oxygen delivery to human tissues.

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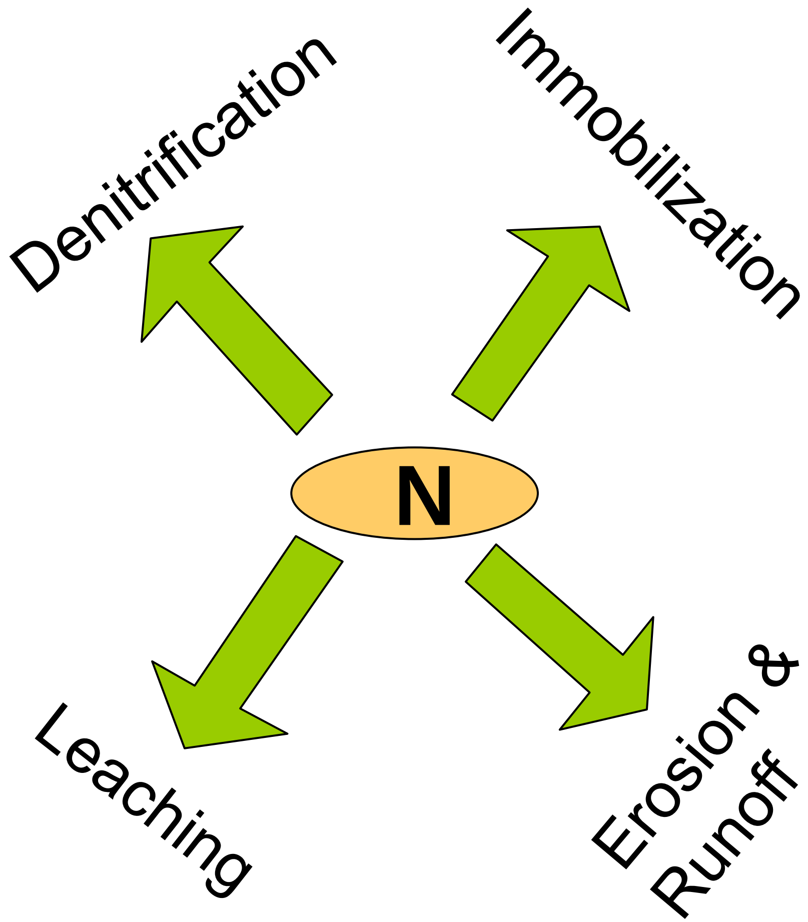
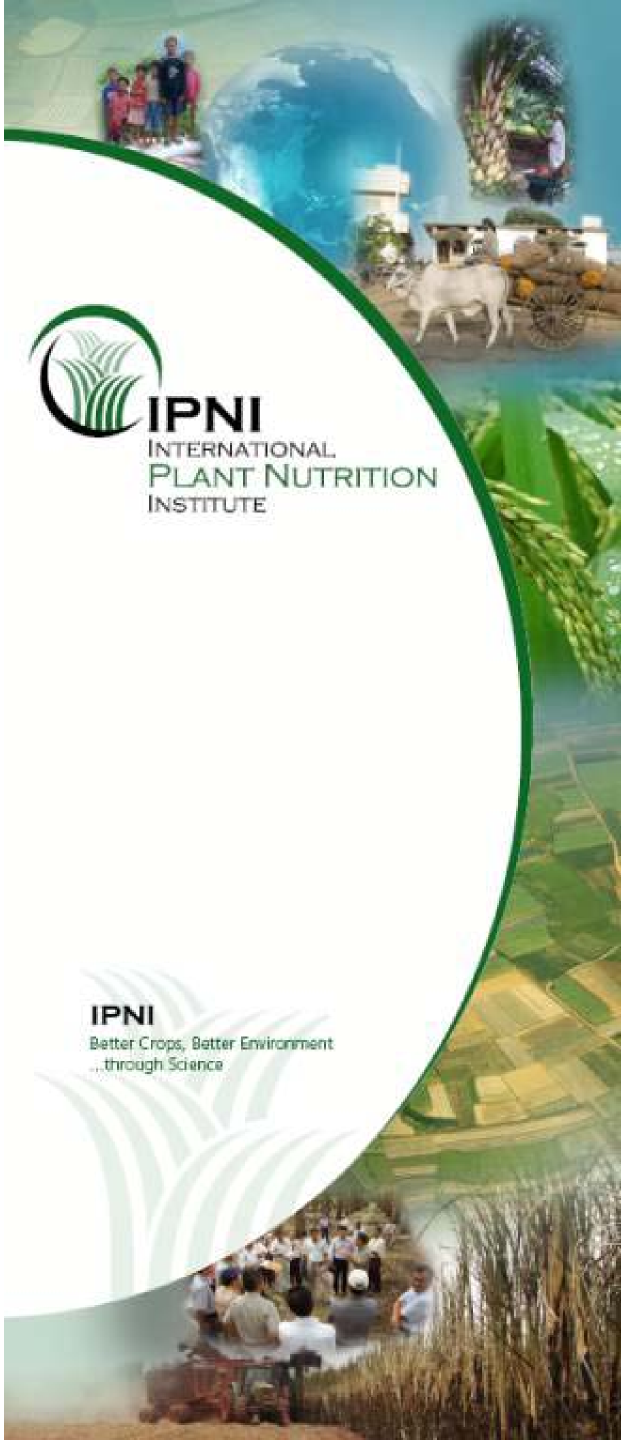
Consequences of N build up in soil

- Risk of N losses increases as the time between N application and crop uptake increases
- The challenge is manipulating N availability before, during and after crop demand
  - while reducing NO_3 accumulation in plants
  - minimizing N losses from the soil

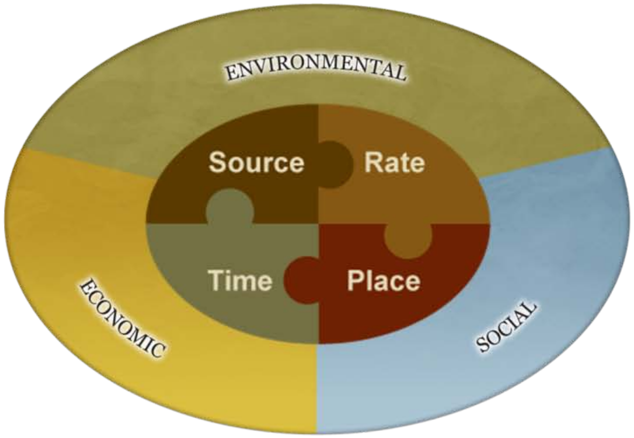


Fertilizer N management strategies



The 4R Nutrient Stewardship concept

- Applying the right source of plant nutrients at the right rate, at the right time, and in the right place
- 4 R's are all necessary for sustainable management of plant nutrition
- Increase the sustainability of plant system to which it is applied in terms of economic, social and environmental dimensions
- All three dimensions need to be included in the assessment of whether or not it is "right"



Strategy ONE….

Recognizing Spatial Variability

Lack of recognition of spatial variability among agricultural holdings has given rise to "one fits all" strategies of nutrient management

- **N fertilizer recommendations were developed for a large scale (state/region)**
- **Developed for individual crops ignoring cropping systems**
- **Mismatch between nutrient additions and removals**
- **No accounting for system nutrient balance**
- **Contributions from other sources not considered**
- **Generalized (blanket) N recommendations over large areas led to under and over-fertilization**

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Making site-specific fertilizer recommendation in highly fragment land use scenario

Number of Soil Testing Laboratories in India	609
Analyzing Capacity	6724000
Samples Analyzed in 2005-06	5007900
Percent Utilization	74.5
Number of Agricultural Holdings	115580000
Years required to analyze samples from all holdings at full capacity	About 17 years

- Soil testing of all holdings to estimate native fertility levels to ensure appropriate recommendation is a logical step.
- But we do not have the infrastructure to accomplish that.

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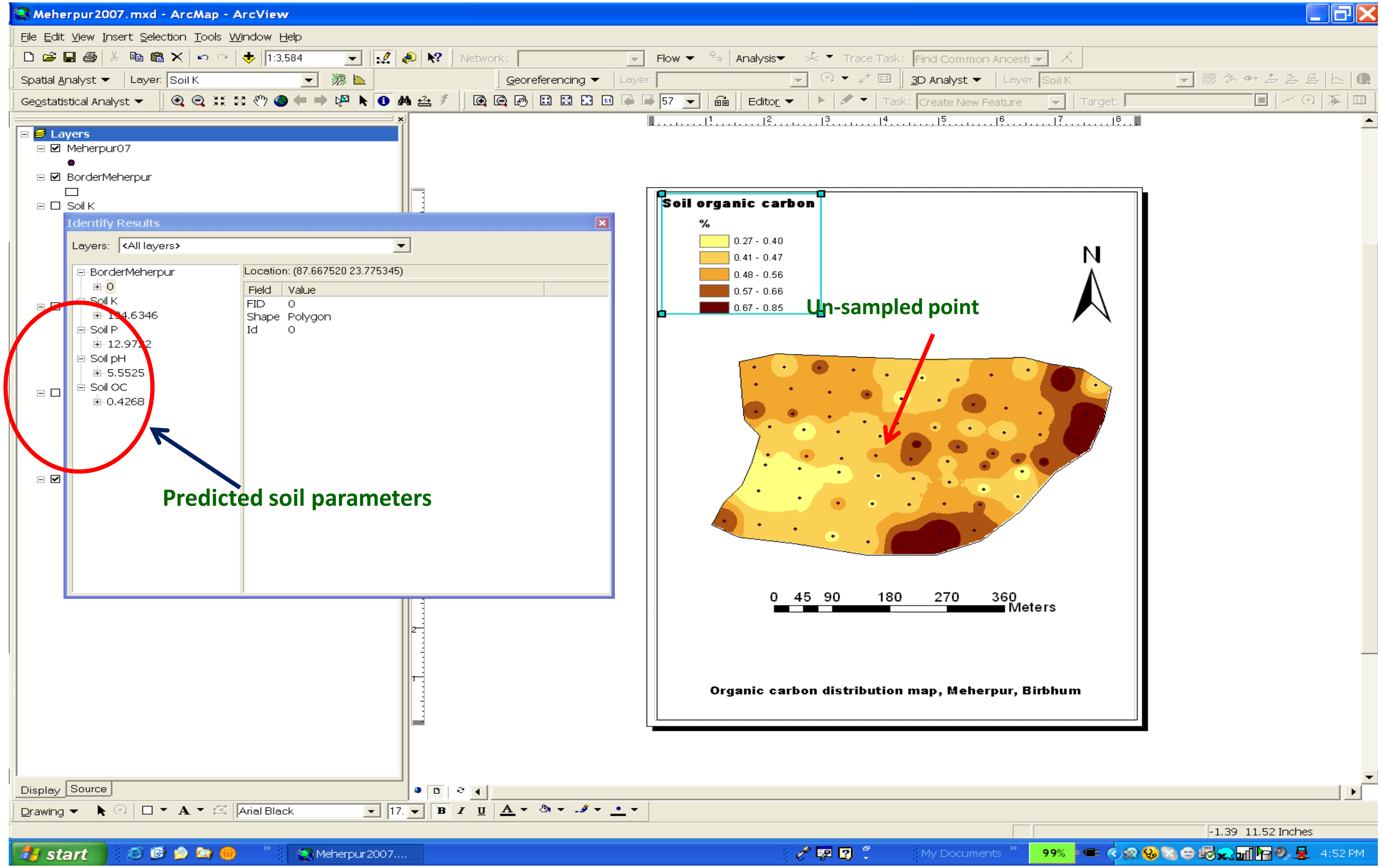
Use of Geographic Information Systems



Predicted values of different parameters under varying soil fertility assessment system

	pH	OC	P_2O_5	K_2O
Actual Soil test	5.80	0.45	16.67	303.78
50 m map based	5.46	0.47	11.19	290.00
100 m map based	5.44	0.47	10.04	289.30
250 m map based	5.65	0.52	14.26	235.00

IPNI Research with VB , 2008

Classification on the basis of Low, Medium and High groups for different nutrients

	pH	Avl. N	P_2O_5	K_2O
Soil test based	Slightly acidic	Low	Low	Medium
50 m^2 grid map based	acidic	Low	Low	Medium
100 m^2 grid map based	acidic	Low	Low	Medium
250 m^2 grid map based	Slightly acidic	Medium	Low	Medium

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Yield of Rice, Potato, & Sesame under different Crop Fertilization Strategies

Treatment	Rice				Potato			Sesame			
	Yield, t/ha		Economics[1], Rs.		Yield, t/ha	Economics, Rs.		Yield, t/ha		Economics, Rs.	
	Grain	Straw	Net return	Return per Rs. invested	Tuber	Net return	Return per Rs. invested	Seed	Stick	Net return	Return per Rs. invested
Farm	4.2	4.6	20,592	1.90	28.7	38,210	1.50	0.8	3.0	3,928	1.22
State	4.4	5.0	21,544	1.91	22.5	20,962	1.30	1.2	3.9	8,278	1.51
Soil test	4.7	6.0	25,614	2.05	28.3	41,556	1.58	1.4	4.2	11,267	1.66
GIS (100m grid)	4.7	6.0	24,760	2.02	27.6	39,128	1.55	1.4	4.1	11,457	1.68
CD at 5%	0.26	0.32	-	-	6.4	-	-	0.3	0.4	-	-

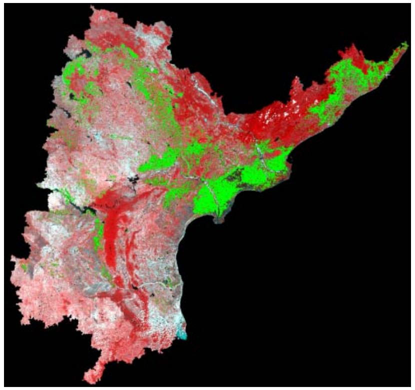
[1]Economic comparisons considered all fixed and variable costs including fertilizers (urea = Rs. 6/kg, SSP = Rs. 6/kg, KCl = Rs. 6/kg) and revenues from rice grain (Rs. 9/kg) and straw (Rs. 1.2/kg), potato tubers (Rs. 4/kg), and sesame seed (Rs. 20/kg) and sticks (Rs. 100/t).

Economics of sampling

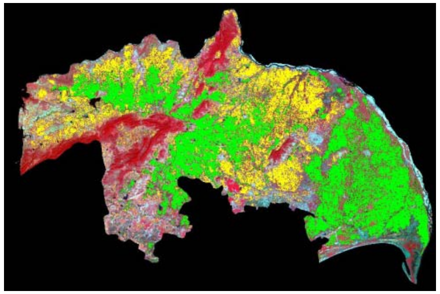
Total number of land holdings	**543**
Total cultivated area of the village in hectares	**76 hectare**
Actual cost of field-based soil testing (NPK analysis, commercial lab)	**543 X Rs. 50 = Rs. 27,150**
Actual cost of soil testing for GIS 50m x 50m sampling 100m x 100m sampling 250m x 250m sampling	**304 X Rs.50 = Rs. 15,200** **76 X Rs. 50 = Rs. 3,800** **19 x Rs. 50 = Rs. 950**

UPSCALING OF SSNM

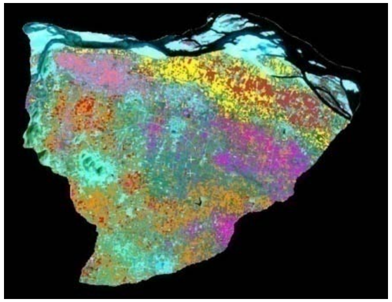
State level



District level



Mandal level



Village level

Field level

What should be the sampling density?
What should be the interpolation technique?

Ravishankar, 2010

Nutrient Mapping in the State of West Bengal

1000 x 1000 m grid is used.
Sample size – 76,000.
A collaborative project with NBSS & LUP

IPNI plans to work closely with the Govt. of West Bengal to standardize a method of fertilizer recommendation from state level maps….Decision support tools

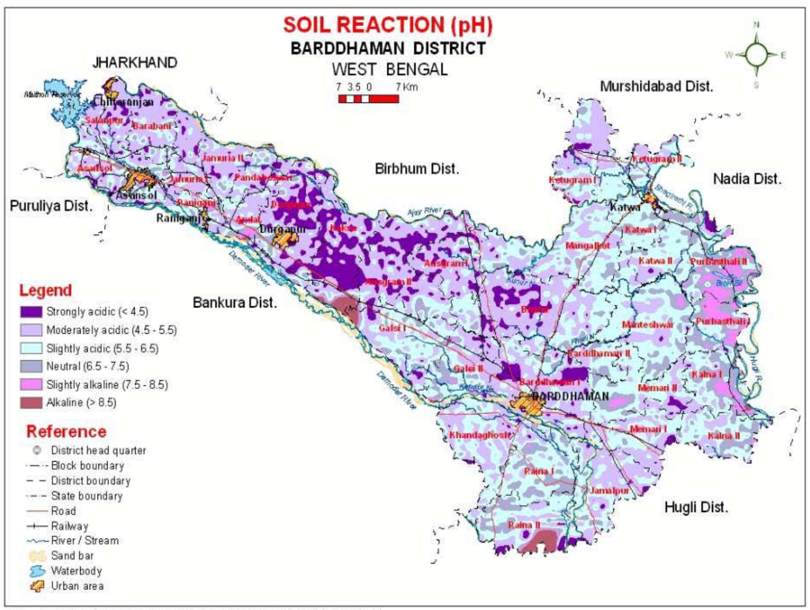


Fig. Soil reaction (pH) map of Barddhaman district, West Bengal

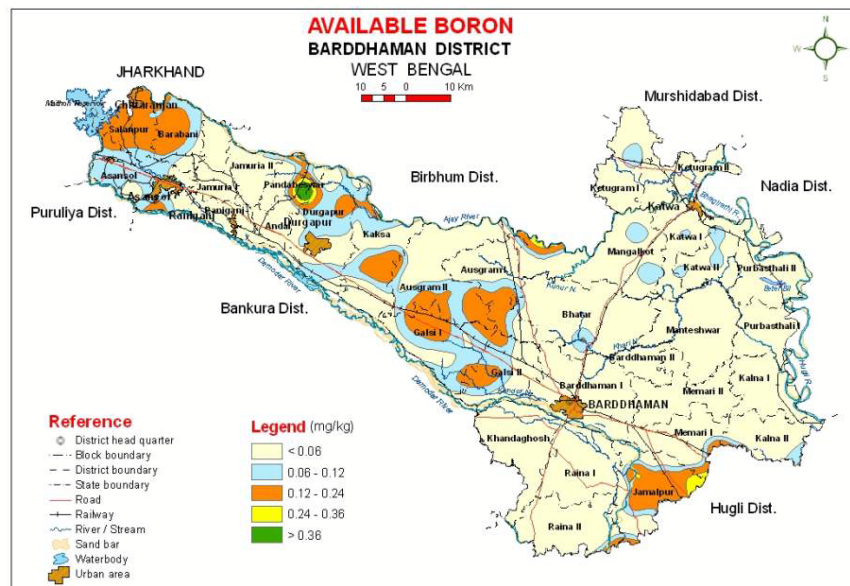


Fig. 15 Spatial distribution of available boron

Chlorophyll Meter & NUEs….

Country, experimental year(s), critical SPAD value	AE_N		RE_N		PFP_N		Reference
	FFP	CM	FFP	CM	FFP	CM	
	kg grain kg N^{-1}		kg N kg N^{-1}		kg grain kg N^{-1}		
India, 2001-03, 37	24.3a	42.4b	0.43a	0.55b	56.6a	77.3b	Maiti et al. (2004)
Thailand, 1997-99, 35	7.4a	9.0a	0.22a	0.29b	30.1a	33.0a	Satawathananont et al. (2004)
Indonesia, 1997-99, 32-35	10.2a	13.0b	0.31a	0.46b	28.9a	29.0a	Abdulrachman et al. (2004)
China, 1997-99, 36	6.0a	11.0b	0.18a	0.29b	36.9a	40.0a	Wang et al. (2001)
India, 1997-99, 35	13.9a	16.0b	0.39a	0.46b	32.8a	38.0b	Nagarajan et al. (2004)
Vietnam, 1997-99, 33-37	14.0a	18.0b	0.33a	0.39b	43.1a	46.0b	Son et al. (2004)
India, 2003 and 2004, 36-37.5	8.8a	16.1b	0.20a	0.30b	34.7a	44.2b	Khurana et al. (2005)
Vietnam, 1997-99, 33-37	15.0a	20.0b	0.34a	0.44b	45.2a	46.0a	Tan et al. (2004)
Philippines, 1996, 35	18.2a	19.7a	-	-	48.0a	44.7a	Balasubramanian et al. (1999)
India, 1999, 37.5	20.0a	23.7b	0.44a	0.51b	-	-	Bijay-Singh et al. (2002)
Philippines, 1997-99, 35	12.0a	15.0b	0.32a	0.46b	36.9a	34.0a	Gines et al. (2004)
India, 1997-99, 35	13.6a	15.0b	0.45a	0.46a	27.9a	31.0b	Nagarajan et al. (2004)

Leaf Color Chart & NUEs…..

Country, year, critical LCC value, type of rice, number of farms	N used, kg N ha^{-1}		Grain yield, Mg ha^{-1}		AE_N		PFP_N		Reference
	FFP	LCC	FFP	LCC	FFP	LCC	FFP	LCC	
<u>Same grain yield with reduced N fertilizer application following LCC</u>									
Philippines, 1998, LCC-4, TPR, 11	78	33	3.97a	3.87a	9b	20a	51	117	Balasubram
Philippines, 1999, LCC-4, TPR, 11	74	46	4.49a	4.68a	12b	19a	91	102	-anian et al.
Vietnam, 1998, LCC-3, B-WSR, 28	120	82	5.24a	5.26a	-	-	44	64	(2003)
Vietnam, 1999, LCC-3, B-WSR, 7	99	70	6.34a	6.31a	-	-	64	90	
India, 2001, LCC-4, TPR, 165	149	124	6.36a	6.37a	-	-	43	51	
India, 2002, LCC-4, TPR, 9	72	46	4.46a	4.56a	-	-	62	102	Haque et al. (2003)
India, 2002, LCC-4, TPR, 107	153	113	6.0a	6.0a	-	-	39	53	Varinderpal
India, 2003, LCC-4, TPR, 48	115	91	6.5a	6.5a	-	-	57	71	Singh et al. (2007)
India, 2004, LCC-4, TPR, 53	134	100	8.1a	8.2a	-	-	61	82	
India, 2005, LCC-4, TPR, 142	145	107	7.0a	7.1a	-	-	48	66	
India, 2000, LCC-4, TPR, 8	120	91	6.53a	6.61a	20.8	27.8	57	85	Yadvinder-
India, 2001, LCC-4, TPR, 8	120	85	7.10a	7.04a	15.4	20.7	60	94	Singh et al.
India, 2002, LCC-4, TPR, 11	126	78	6.93a	7.12a	11.3	17.8	52	83	(2007)
<u>Increase in grain yield with reduced N fertilizer application following LCC</u>									
Philippines, 1998, LCC-3, B-WSR, 6	151	125	4.53b	5.15a	6b	14a	30	41	Balasubram
Vietnam, 1999, LCC-3, B-WSR, 18	98	80	4.63b	4.92a	-	-	47	62	-anian et al. (2003)
India, Uttar Pradesh, 2002, LCC-4, TPR, 1	150	135	6.9b	7.6a	20.7b	28.1a	46	56	Shukla et al. (2004)
Bangladesh, LCC-4, TPR, 33	149	100	3.8b	4.1a	10b	16a	25	41	Alam et al. (2006b)

Crediting Nitrogen Mineralization

- Nitrate, as an end product of mineralization and subsequent nitrification of SOM, manure, crop residue, or previously applied fertilizer N that has cycled through soil organic N pools, can make significant contributions toward crop N needs.

- Monitoring N mineralization to better match the required amount of available N with crop needs is a good strategy to reduce soil nitrate buildup. For this, several versions of a pre-sidedress soil nitrate test (PSNT) (Magdoff et al. 1984; Fox et al. 1989; Magdoff et al. 1990) or modifications such as the late-spring nitrate test (LSNT) (Blackmer et al. 1997) have been developed.

- Plot-scale studies using PSNT or LSNT strategies to determine N rates have generally shown reductions in measured or potential soil N losses. For example, in Iowa, these procedures resulted in fertilizer N applications ranging from 50 to 168 kg N/ha and significantly reduced nitrate loss to water compared with single pre-plant applications of only 112 kg N/ha.

Strategy TWO….

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Use of Nitrification Inhibitors

- The primary use for NIs is to slow the conversion of ammonia-based fertilizers to nitrate form, thus potentially reducing soil nitrate buildup and improving NUE.
- These have met with varying success, generally depending on soil type and weather pattern under which they were used.
- An 8-yr project in Ohio (Stehouwer and Johnson 1990) examined different application timings with and without a nitrification inhibitor. The results showed that at similar N rates, spring preplant urea application produced higher yields than fall applications.
- In Minnesota, Randall et al. (1992) found that corn yield and NUE were lowest with fall N application without nitrapyrin, highest with spring N applications, and intermediate with fall N plus nitrapyrin.

Strategy THREE….

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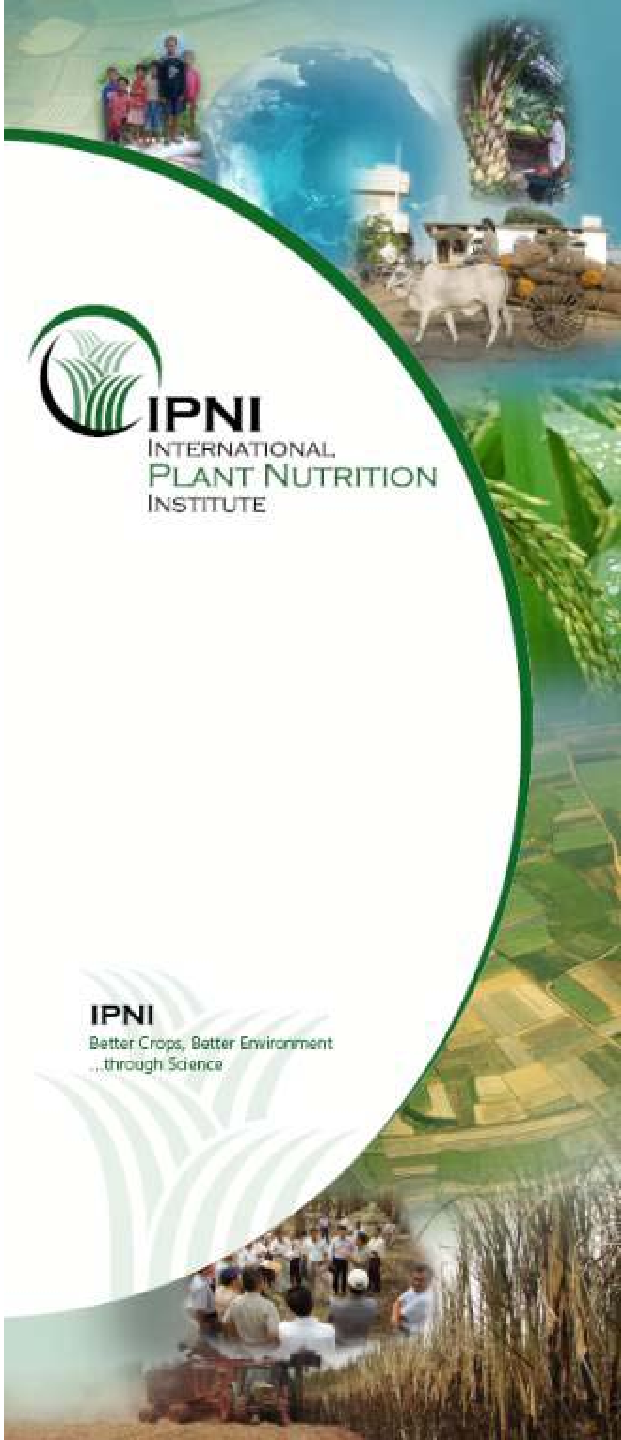
Fertilizer Application Equipment

- A localized compaction and doming (LCD) applicator (Ressler et al. 1997), has been developed to alter soil physical properties immediately above the soil volume where knife-injected liquid N fertilizer was placed.

- Another application technique developed to improve N management was the point injector, which until no-till conditions, was demonstrated to have the potential to reduce ammonia volatilization and N immobilization at the surface without destroying surface residues or adversely affecting corn yield (Baker et al. 1985).

Strategy FOUR….

Crop management strategies



Diversifying Crop Rotations

- Introducing legume crops in well established crop rotations has been shown to decrease N buildup in soils as well as N losses.
- In Iowa, Baker and Melvin (1994) documented much lower nitrate-N concentrations beneath alfalfa than for corn or soybean.
- Changing continuous corn to a corn-soybean rotation has been shown to reduce N losses in field (Randall et al. 1997).

Strategy FIVE…..

Using Cover Crops

- Cover crops have been shown to reduce the potential for N losses from farm fields by mimicking natural ecosystems such as praries.

- Cover crops function by accumulating the inorganic soil N between main crop seasons and holding it in an organic form, thus preventing it from loss or build up in soil.

- Cover crops also protect against soil erosion (Dabney 1998; Kaspar et al. 2001), increase SOM (Reicosky and Forcella 1998; Dinesh et al. 2004), and suppress weed growth (Buhler et al. 1998; Lal et al. 1991).

- Meisinger et al. (2007) reviewed studies on cover crops and showed that these crops reduced both the mass of N leached and nitrate concentration of leachate by 20 to 80% compared with no cover crop control.

Strategy SIX….

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Some More Strategies….

- Manipulating tillage practices (no-till vs. reduced vs. conventional).
- Managing plant residues.
- Nitrate removing tools and approaches (riparian buffers, bioreactors etc.)


Future Research Needs

- The logistics and time required for soil sampling and analysis in relation to the window of opportunity for fertilizer application has prevented widespread adoption of the PSNT-LSNT N management approach. A test is needed that can be performed earlier in the season and that relies on real-time meteorological and soil data to predict plant-available soil N status.

- A model that predicts N mineralization based on temperature (growing degree days) has been developed (Honeycutt et al. 1988). However, application of the model requires a calibration procedure for the soil of interest.

- Remote sensing technologies (RSTs) are another good option. But to be effective, RSTs must be able to correctly differentiate crop area that are N deficient due to low soil N from all other conditions that may lead to chlorosis in plants, such as water-saturated soils, Mg & K deficiencies, or disease & insect infestations.

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