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Enhanced Nitrogen Fertilizer Technologies Support the '4R' Concept to Optimize Crop Production and Minimize Environmental Losses

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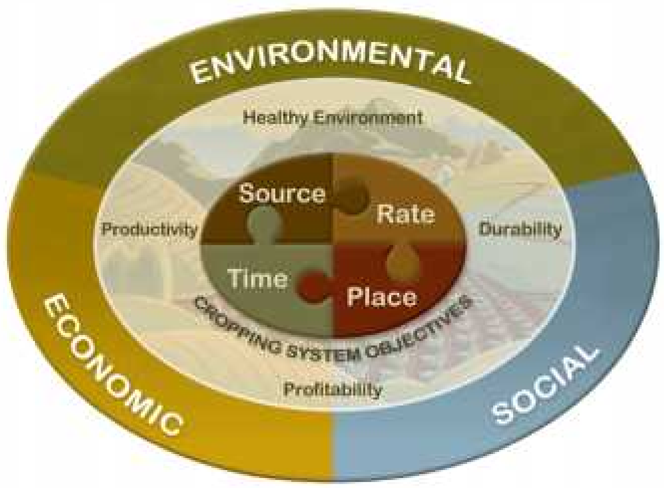
Aim of this Presentation and Paper

- Highlight opportunities to improve crop recovery of applied fertilizer N and to reduce losses of N to the environment
  - Share recent (~ last 5 years) examples of published results addressing management of different N sources, rates, timing, and place of application [the 4Rs (*right source, right rate, right time, right place*) of fertilizer N stewardship
  - Focus on enhanced efficiency N fertilizers (EEFs)
  - Briefly mention examples of recent industry N management actions and outcomes, and emerging opportunities for crop sensor-based N management



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Grand Challenges and Opportunities to Improve Cropping System N Management on the Farm

- Large gaps exist between typical farmer crop yields and realistically attainable crop yields (Cassman *et al.* 2003)
- Keys to achieving these critical needs of the human family, while minimizing the human environmental footprint
  - Rely on improving crop recovery and the overall efficiency and effectiveness of fertilizer and manure N use
- Need to "increase the overall performance of cropping systems"; both water and nutrient management, in the face of climate change (Fixen et al. 2014)
- Many questions remain about the dynamics and nutrient-use efficiency of various types of fertilizers (Tomich *et al*. 2011).

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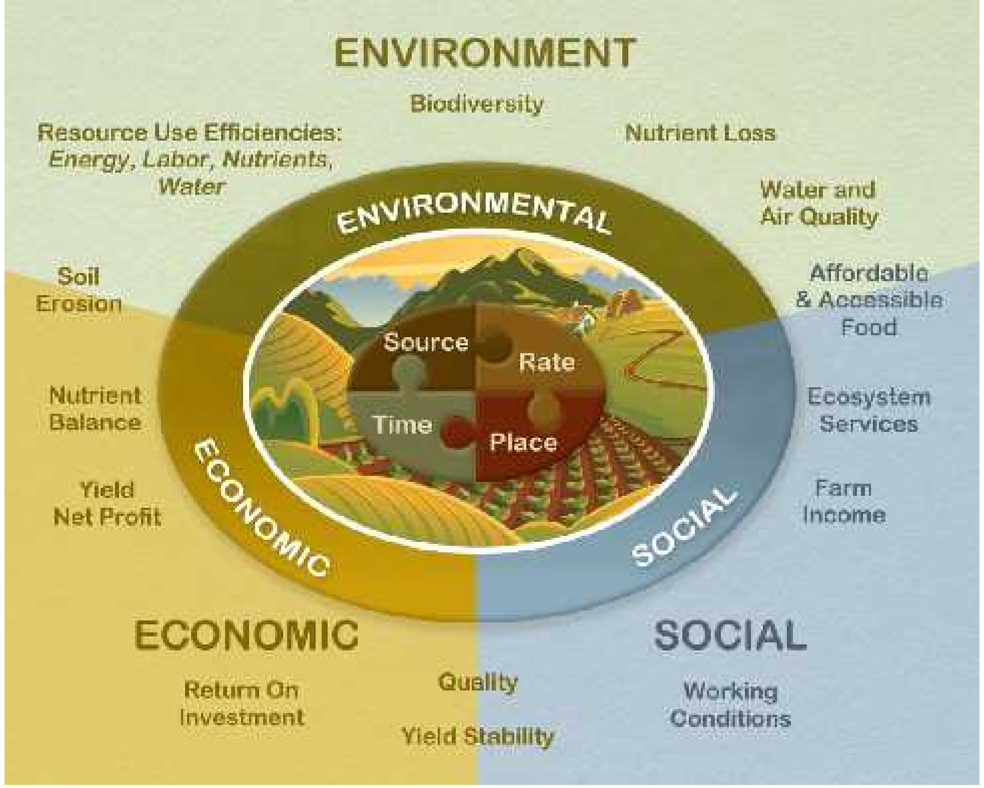
Our Premise …… or Position
More in the Crop = Less in the Environment

- **Agronomically appropriate N rates are a fundamental part of the 4Rs**

http://www.ipni.net/4R



Many Factors Affect N_2O Emission: Manageable and Unmanageable

Management Practices	Environmental Factors
Fertilizer type **SOURCE**	Temperature
Application rate **RATE**	Precipitation
Application technique **PLACE**	Soil moisture content
Timing of application **TIME**	Organic C content
Tillage practices	Oxygen availability
Use of other chemicals	Porosity
Crop type	pH
Irrigation	Freeze and thaw cycle
Residual N and C from crops and fertilizer	Microorganisms

Source: Eichner. 1990. J. Environ. Qual.19:272-280

As Emphasized by J. Freney (1997):

- In addition to using the appropriate fertilizer N rate, there are multiple ways to achieve improved crop recovery and the overall efficiency and effectiveness of fertilizer N use
  - i) use of the correct form and time of application,
  - ii) use of continuous soil cover,
  - iii) correct tillage, drainage, and irrigation,
  - iv) greater knowledge on the effects of biomass burning on grasslands and croplands,
  - v) use of foliar N fertilizer applications,
  - vi) use of slow or controlled release fertilizers, and
  - vii) use of urease and nitrification inhibitors.

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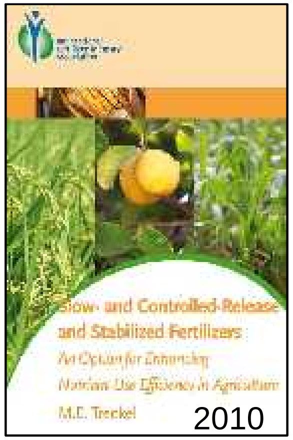
Definitions of Slow- and Controlled-Release N Fertilizers and Nitrification and Urease Inhibitors

- **Slow- or controlled-release fertilizer:** delays nutrient availability for plant uptake and use after application, or which extends its availability to the plant significantly longer than a reference ‘rapidly available nutrient fertilizer’ such as ammonium nitrate or urea, ammonium phosphate or potassium chloride.
    - includes controlled water solubility of the material by semi-permeable coatings, occlusion, protein materials, or other chemical forms, by slow hydrolysis of water-soluble low molecular weight compounds, or by other unknown means.
- **Stabilized nitrogen fertilizer:** A fertilizer with an added nitrogen stabilizer, to extend the time the N remains in the soil in the urea-N or ammoniacal-N form.
    - **Nitrification inhibitor:** inhibits the biological oxidation of ammoniacal-N to nitrate-N
    - **Urease inhibitor:** inhibits hydrolytic action on urea by the enzyme urease



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Operating Definition of Enhanced Efficiency N Fertilizers (EEFs; as reported by Snyder *et al.* 2014)

- **As defined by the Association of American Plant Food Control Officials (AAPFCO):**
- " … 'fertilizer products with characteristics that allow increased plant uptake and reduce the potential of nutrient losses to the environment (e.g. gaseous losses, leaching, or runoff) when compared to an appropriate reference product' (Halvorson et al. 2014)."
- Reference products are:
  - "soluble fertilizer products (before treatment by reaction, coating, encapsulation, addition of inhibitors, compaction, occlusion, or by other means) or the corresponding product used for comparison to substantiate enhanced efficiency claims"

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Nitrification Inhibitor Meta Analysis 1970s to 2001 (Wolt 2004)

- **Average effects of the nitrification inhibitor – nitrapyrin, as compared to N fertilization without nitrapyrin,**
- increased crop yield **7%**,
- increased soil N retention **28%,**
- decreased nitrate-N leaching **16%,**
- decreased greenhouse gas emissions by **51%;**
- but had no effect on agronomic or environmental N performance about **25%** of the time.

Nitrification Inhibitors

- Global literature synthesis by Pan *et al*. (2016)
  - use of nitrification inhibitors may increase the risks of ammonia volatilization from some fertilizer N sources.
- Nitrification inhibitor use may not increase grain yield, or modestly (7%) increase grain yield (Wolt 2004; Abalos et al. 2014; Thapa et al. 2016)
- Yet, better cropping system performance may be reflected in indicators of increased N use efficiency (Burzaco *et al*. 2014):
  - plant N uptake, apparent crop N recovery (differential ratio of plant N uptake to N applied), or internal crop N efficiency (the differential ratio of grain yield to plant N uptake).

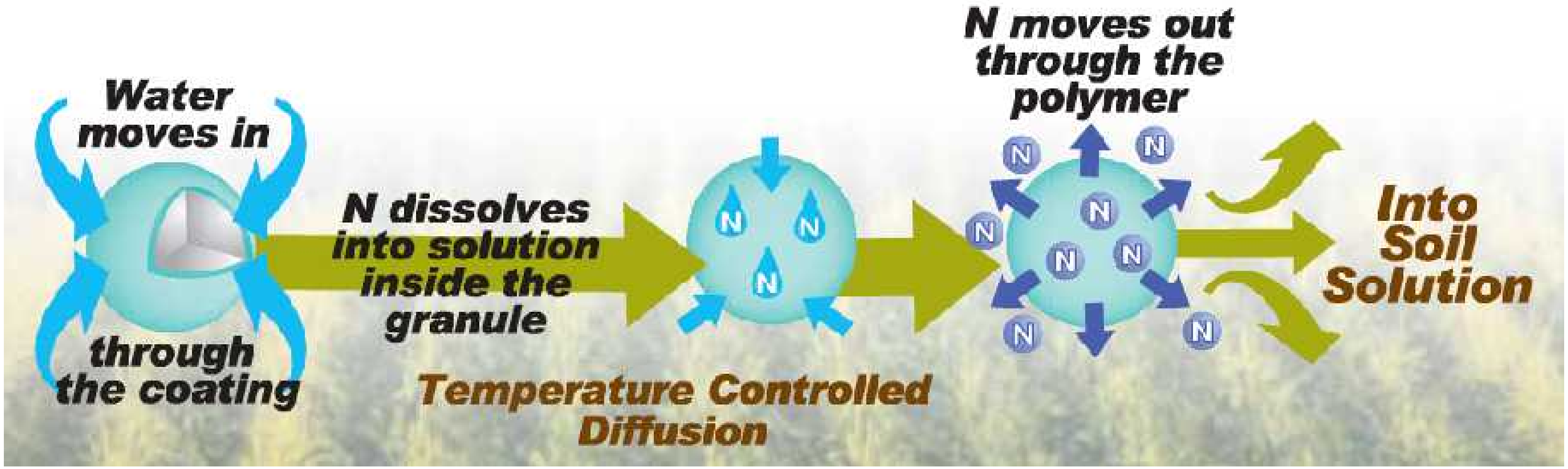
Urease Inhibitors

- **Reviewed by Singh (2008) and Saggar et al. (2008)**
  - urease-inhibiting compounds classified according to their structures and binding modes with the urease enzyme
- **Saggar et al. (2013)**
  - provided details on one of the more widely used and effective compounds, N-(n-butyl) thiophosphoric triamide (nBTPT) - tradename Agrotain®
  - summarized multiple studies on reduced ammonia emissions with nBTPT in grazed pastures (primarily in New Zealand) that were fertilized with urea, or with animal urine.

Polymer Coated Urea or Controlled Release Urea

- Are generally water soluble,
- Have urea release rates that are affected by the
  - polymer chemistry,
  - coating process,
  - coating thickness, and
  - temperature of the environment where they are applied.
- The timing of urea N release is important and can be an issue,
  - especially if the PCU source does not release the N synchronous with crop demand and the prevailing environmental conditions (Golden et al. 2011, Maharjan *et al*. 2016, Suter et al. 2013).

PCU Controlled-Release Mechanism, by Temperature



Source: Agrium

Examples of Enhanced Efficiency Fertilizer N Products

- **Slow Release**
  - Methylene urea
    - Liquid
    - Granular
  - Isobutylidene diurea (IBDU)
  - Sulfur coated urea
- **Controlled release**
  - Polymer coated urea

- **Urease inhibitors**
  - N-(n-butyl) thiophosphoric triamide (NBPT)
  - phenyl phosphorodiamidate (PPDA)
  - N-(2-nitrophenyl)phosphoric acid triamide (2-NPT)
- **Nitrification inhibitors**
  - 2-chloro -6-(tricholormethyl-pyradine) (Nitrapyrin)
  - Dicyandiamide (DCD)
  - 3,4-dimethylepyrazole phosphate (DMPP)
  - Ammonium thiosulfate (ATS)

Example Sulfur- and Polymer-Coated Products

Country	Company	Key products	Key technology
China	Hanfeng	Hangfeng SCF	
Korea	Namhae Chemical	Namhae	Sulfur coated fertilizer (SCF)
Indonesia	PT Hanampi Sejahtera Kanuripan	Haracoat	
China	Kingenta	Syncote	
China	Moith	Stancote	
China	LGAGRO	Supucote	
Israel	ICL SF	Osmocote	
Israel	Haifa	Multicote	
China	Greenorchids	BENEFIT	
Japan	Chisso asahi	Nutricote	
USA	Simplot	APEX	
Canada	Agrium	ESN	Polymer coated fertilizer (PCF)
Norway	Yara	Plantacote Top N™	
Germany	Aglukon	Plantacote	
Germany	Compo Expert	Basacote	
Malaysia	SK Specialties	SK Cote	
Nederland	Mivena	Granucote	
Nederland	Ekompany(Kingenta)	Ekote	
Korea	Dongbu Farm Hannong	Long Star	
Korea	KG Chemical	KG-PCF	

www.agropages.com, **In Focus**, Market Insight, Oct. 2016:

Technical Summary of Global Enhanced Efficient Nitrogen Fertilizers

Example Slow-Release Products

Malaysia	Greenfeed	Greenfeed®	Zeolite
Germany	Aglukon	Nitroform	Methylene urea (MU)
Germany	Aglukon	Azolon	
Germany	Compo-Expert	Floranid	Isobutylidene diurea (IBDU)
Germany	Aglukon	Plantosan	Urea formaldehyde (UF)

www.agropages.com, **In Focus**, Market Insight, Oct. 2016:

Technical Summary of Global Enhanced Efficient Nitrogen Fertilizers

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Example Nitrification Inhibitor and Urease Inhibitor Products

Germany	Compo-Expert	Nitrophos	Dicyandiamide (DCD)	Nitrification inhibitor (NI)
Germany	Compo-Expert	NovaTec	3,4 dimethylpyrazole phosphate (DMPP)	
	BASF	Vizura®		
USA	Dow Agro Science	N-Serve	2-chloro-6-trichloromethyl pyridine (Nitrapyrin)	
China	Zhejiang Aofutuo Chemical	NMAX	2-chloro-6-trichloromethyl pyridine (Nitrapyrin)	
USA	Koch Agronomic Services	Agrotain	N (N butyl)thiophosphoric triamide (NBPT)	Urease inhibitor (UI)
Belgium	Solvay	AgRHO® N-Protect	N-(N-butyl)thiophosphoric triamide (NBPT)	
Germany	BASF	LIMUS	N-(N-butyl)thiophosphoric triamide (NBPT)+ N-(2-nitrophenyl)phosphorictriamide(NPPT)	

www.agropages.com, **In Focus**, Market Insight, Oct. 2016:

Technical Summary of Global Enhanced Efficient Nitrogen Fertilizers

Effects of EEFs and Related Technologies on:

- Crop yield increase
- Reduction of Nitrate-N (NO_3-N) leaching
- Reduction of ammonia (NH_3) volatilization
- Reduction of direct nitrous oxide (N_2O) emission

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Nitrification Inhibitor: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information-review/meta analysis (R) or original study (O)
nil to 13				Gagnon et al. (2012)-O
-6 to 3			**24**	Burzaco et al. (2013)-O
7				Linquist et al. (2013)-R
3	**17**			Quemada et al. (2013)-R
<2				Burzaco et al. (2014- R & O
			19-100	Snyder et al. (2014)- R
			37 to 44	Lam et al. (2015)-O

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Nitrification Inhibitor: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
5 to 14	**48**	**-20**	**44**	Qiao *et al*. (2015)- R
-3 to -7				Suter *et al*. (2015)-O
		-3 to -65	**8 to 57**	Lam *et al*. (2016)-R
		-38		Pan *et al*. (2016)-R
7			**38**	Thapa *et al.* (2016)-R
nil			**nil to 36**	Wang *et al*. (2016)-O
			-433 to 66	Van der Weerden *et al*. (2016)-O

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Urease Inhibitor: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
		68		Franzen *et al*. (2011)-O
5				Linquist *et al*. (2013)-R
		25 to 100 (weighted mean **63** with ≥0.02% w/w nBTPT **)**		Saggar *et al*. (2013)-R
-17 to -5		**23 to 70**		Suter *et al*. (2013)-O

Urease Inhibitor: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
			nil to 5	Snyder *et al*. (2014)-R
-4 to 6				Suter *et al*. (2015)-O
		54		Pan *et al*. (2016)-R
<2		**nil to 36**		Thapa *et al.* (2016)-R
			-400 to 6	Van der Weerden *et al*. (2016)-O

Urease + Nitrification Inhibitor: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
3				Linquist *et al*. (2013)-R
-11	**-28**		**18**	Maharjan *et al*. (2014)-O
nil to 5			**25 to 42**	Gao *et al*. (2015)-O
			37 to 46	Snyder *et al*. (2014)-R
nil			**30 to 34**	Thapa *et al*. (2016)-R)
-2			**17**	Venterea *et al*. (2016)-O
3				Linquist *et al*. (2013)-R

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Polymer Coated Urea: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
nil			17 to 39	Hyatt *et al*. (2010-O)
	-20 to 10		18 to 40	Venterea *et al*. (2011)-O
nil to 34				Gagnon *et al*. (2012)-O
12 to 30			-28 to 14	Nash *et al*. (2012)-O
-1 to 20		38 to 91		Xu *et al*. (2012)-O
12 to 22				Yang *et al*. (2012)-O
7				Linquist *et al*. (2013)-R

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Polymer Coated Urea: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information-review/meta analysis (R) or original study (O)
7				Nelson and Motavalli (2013)-O
-15 to 12				Nelson *et al*. (2013)-O
-7	**34**			Quemada *et al*. (2013)-R
-3 to 13				Ye *et al.* (2013)-O
-10	**-41**		**20**	Maharjan *et al*. (2014)-O
	nil			Nash *et al*. (2014)-O
			14 to 42	Snyder *et al*. (2014)-R

Polymer Coated Urea: % Effects Compared to Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
-6 to 5			26	Gao *et al*. (2015)-O
3 to 6			29 to 45	Fernandez *et al*. (2015)-O
-27 to -10				Suter *et al*. (2015)-O
10 to 59				Maharjan *et al.* (2016)-O
		68		Pan *et al*. (2016)-R
nil			19	Thapa *et al*. (2016)-R)
			-50 to 31	Wang *et al*. (2016)-O

Maleic-Itaconic Acid Copolymer: % Effects Compared to Reference N Source

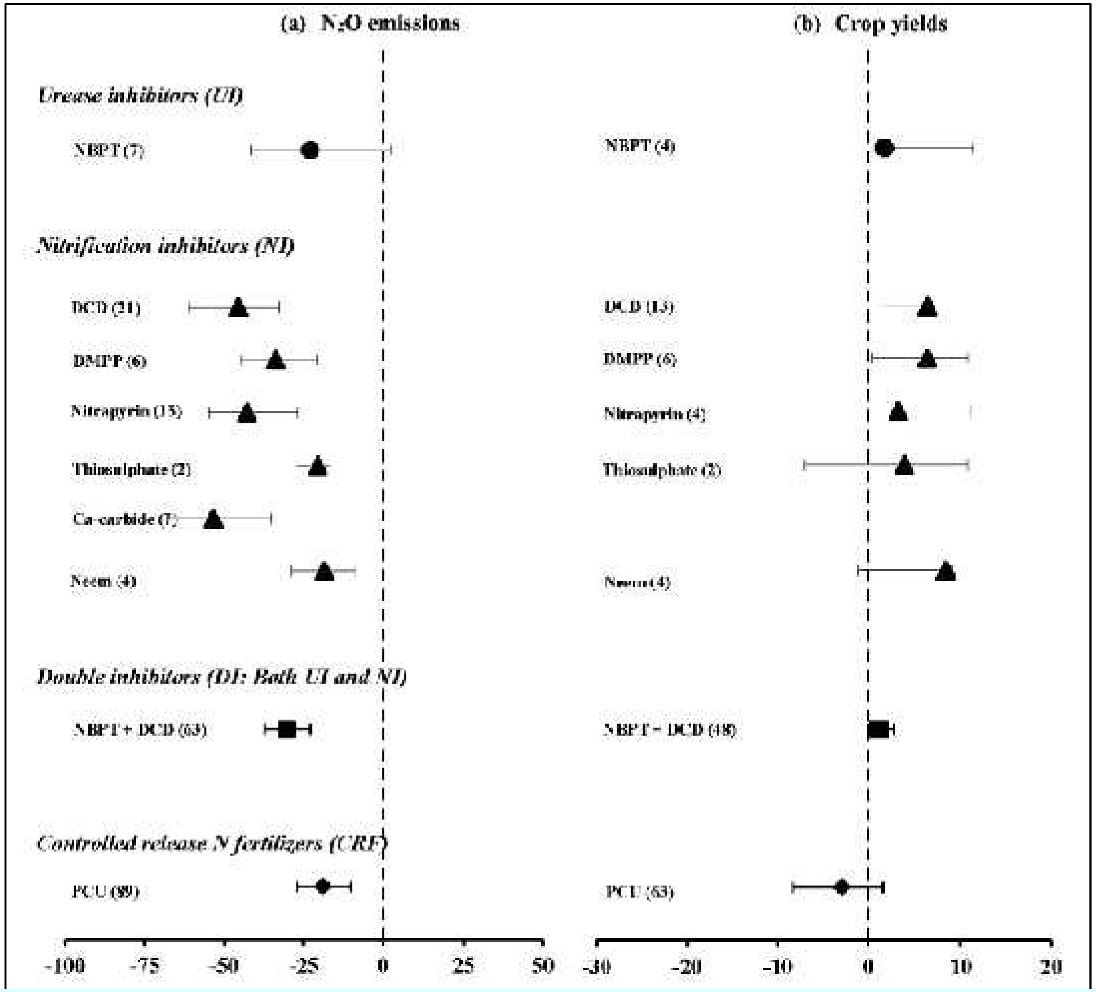
Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information- review/meta analysis (R) or original study (O)
-5 to nil		-10 to nil		Franzen *et al*. (2011)-O
0.05; -5 to 10		nil		Chien *et al*. (2014)-R

Fertilizer N (with or without EEFs) Instead of Manure N: % Effects Compared to Manure as Reference N Source

Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information-review/meta analysis (R) or original study (O)
			nil to 81	Snyder *et al*. (2014)-R
			37 to 112	Van der Weerden *et al*. (2016)-O

% Effects Compared to Reference N Source

Improved fertilizer N technologies and/or fertilizer management	Crop yield increase	Nitrate leaching reduction	Ammonia volatilization reduction	Direct nitrous oxide emission reduction	Source of information-review/meta analysis (R) or original study (O)
recommended rate &/or, reduced rate, &/or optimal timing, &/or fertigation		**40**			Quemada *et al*. (2013)-R
controlled release &/or nitrification inhibitor	**-1**	**24**			
fertigation	**-7**	**7**			



Effect of individual enhanced efficiency fertilizer (EEF) types (%)

Thapa et al. (2016)

Effect of Enhanced Efficiency Fertilizers on Nitrous Oxide Emissions and Crop Yields: A Meta-analysis

Soil Science Society of America Journal 80:1121–1134

Thapa et al. (2016)

Effect of Enhanced Efficiency Fertilizers on Nitrous Oxide Emissions and Crop Yields: A Meta-analysis

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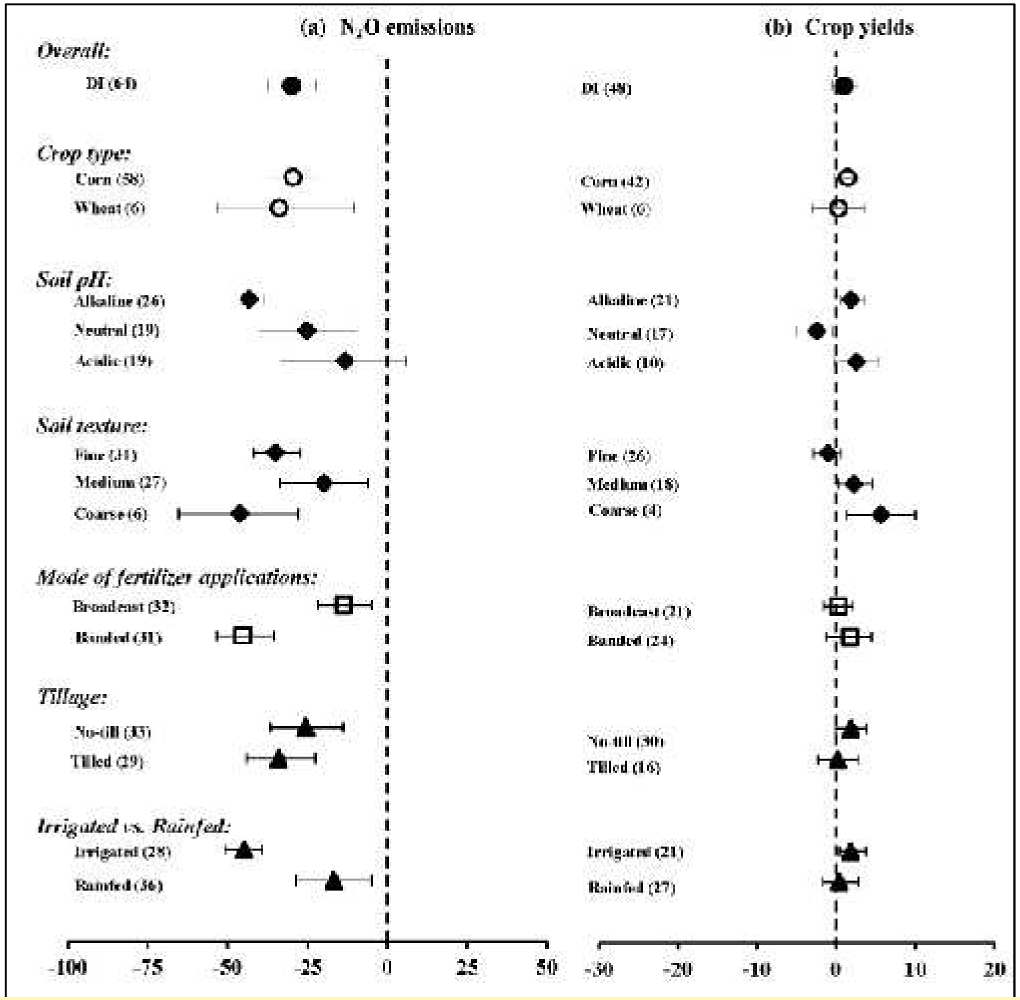

Effect of urease plus nitrification inhibitors (%)

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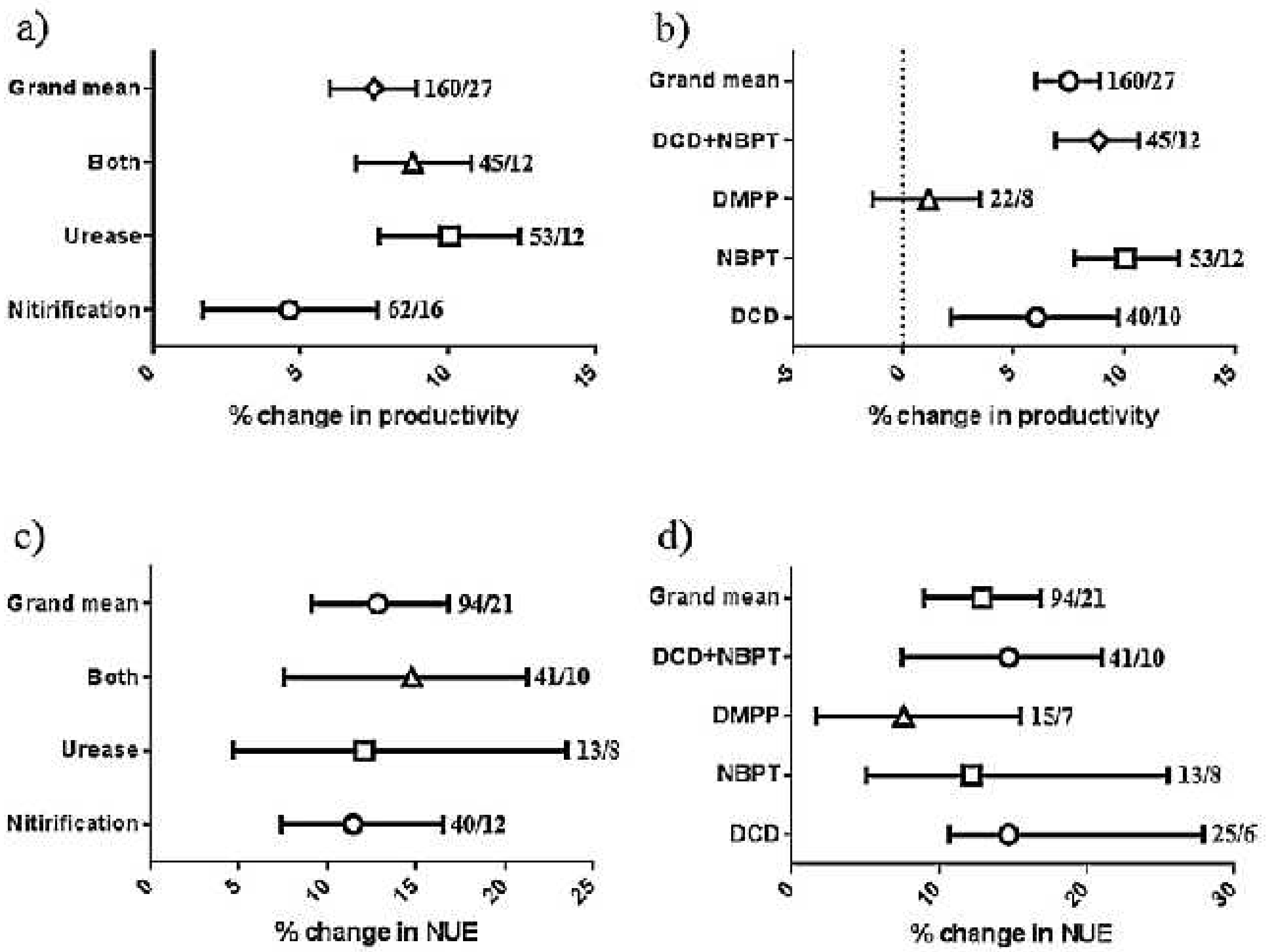

Abalos et al. (2014)

Meta-analysis of the effect of urease and nitrification inhibitors on crop productivity and nitrogen use efficiency

Agriculture, Ecosystems and Environment 189: 136–144

NUE= % of fertilizer N applied, taken up in the grain or above-ground biomass

Environmental Life Cycle Analysis Modeling of Crop Sensor-Based N Management, Li et al. (2016)

- Relied on corn grain yield and N rate data from a sensor-based variable-rate N experiment on corn in Lincoln County, Missouri, USA.
- **Modeling indicated that sensor-based variable-rate N application could reduce:**
  - fertilizer N use by 11% with no loss in corn grain yield;
  - soil N_2O emissions by 10%,
  - volatilized ammonia loss by 23%, and
  - leaching losses of nitrate-N reduced by 16%.

Trenkel (2010) cited Grant (2005), stating

- **If the economic benefits of EEFs to society are substantial …**
  - “some costs should perhaps be borne by society, possibly through incentives for development and advisory work on slow- and controlled-release and stabilized fertilizers, and for encouraging their wider adoption by farmers”.

CONCLUSION

- Wide range in effects of EEFs on crop yields, N recovery, and reduced risks of N loss reflect the importance of regional or site-specific use of EEFs in 4R N management planning and implementation.
- N loss trade-offs may occur with some EEFs (e.g. risk of heightened volatilization of ammonia when using some nitrification inhibitors), which underscores the need for studies that simultaneously measure volatilization, leaching, and N_2O emissions.
- Coupling EEFs and other 4R N management tools with precision technologies, information systems, and crop growth and N utilization and transformation models – especially models with real-time weather sensitivity - may improve opportunities for refined N management in the future.

Thank You

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Better Crops, Better Environment … through Science

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