A

Genetic-Mitigation Strategy

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JIRCAS, Japan

Collaborators & Partners

CIAT
CIMMYT
ICRISAT
CCAF

JIRCAS-NARO International Symposium on Agricultural Greenhouse Gas Mitigation,
31st August 2017, Tsukuba, Japan
Global GHG emissions
Monetization of climate effects using “the best available science and economics”

*49 Gt of CO₂ eq.yr⁻¹
2004 data; Nature 2011

49 Gt*

- Agriculture and forestry: 31%
- Industry: 19%
- Energy supply: 13%
- Transport: 8%
- Waste and waste water: 3%
- Buildings: 26%

1 Gt = 1 billion tons
IWG = Interagency Working Group on Social cost of GHG
Cost of global damage from GHG is $50 t⁻¹ CO₂*
*based on IWG recent estimate (Science 2017, 357:655)

Cost of Global damage from GHG emissions estimated at
$US 2450 billion y⁻¹ ($US 2.45 trillion y⁻¹)
Agriculture alone is responsible for 14 Gt CO$_2$.eq.y$^{-1}$
About 24% of total GHG emissions

A major portion (80%) of agricultural GHG emissions are associated with
Production and Use of N-fertilizers
(based on life-cycle analysis, which is energy and carbon intensive)

The social cost of 14 Gt of GHG emissions from agriculture is
$US 700 billion y^{-1}$
Global food production has doubled from 1960 - 2000

Nitrogen fertilizer consumption increased 10-fold

Nitrogen fertilizer consumption worldwide in 2010

>120 Tg (million metric tons)

Energy cost of nitrogen fertilizer – 1.8 to 2 L diesel oil per kg N fertilizer

1.70 billion barrels of diesel oil

(energy equivalent) is needed to produce this nitrogen fertilizer

Nearly 70% of the N fertilizer applied is lost to the environment

Amounts to a direct annual economic loss of

US$ 90 billion*

(*based on - a) world annual N fertilizer production is 150 million Mg; b) 0.45 US$ kg⁻¹ urea)

N₂O emissions double from 2011 levels

Why NUE is <30% in most agricultural systems?

Uncontrolled rapid nitrification in agricultural soils

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Soil OM

Organic N

Microbial N

Mineralization

Crop Residues

Plant N uptake & Assimilation

Inorganic N

NH₄⁺

>95% of the total soil inorganic N pool

Nitrification

NO₃⁻

>15 groups of bacteria and fungi use NO₃⁻ as source of energy

Anaerobic process

Denitrification (NO₃⁻ → N₂)

N₂O

Nitrosomonas

Archaea

Nitrobacter

Aerobic process

Nitrification (NH₄⁺ → NO₃⁻)

>80% of global N₂O emissions is generated from Farming

Intensification of agricultural practices led to acceleration of nitrification in modern production systems

Intensification of agricultural practices led to acceleration of nitrification in modern production systems
Switch to low-nitrifying agricultural systems

How to achieve low-nitrifying agricultural soils?
Concept of Biological Nitrification Inhibition (BNI)

A Genetic-Mitigation Strategy

BNI Concept

Microbial-N

Ammonium (NH₄⁺)

Nitrite (NO₂⁻)

Nitrate (NO₃⁻)

Denitrification

Nitrate leaching

N₂O, NO and N₂

N lost from agricultural system

BNI-Mitigation Technology?

Immobilization

Mineralization

Nitrite oxidizing bacteria

Nitrate oxidizing bacteria

BNI International Consortium

N lost from agricultural system
How to engineer a plant function into Technology & Research Strategy

Characterization of BNI function

- Strength of BNIs production in crops/pastures
- Genetic variability in BNI-trait
- Chemical-identity of BNIs
- How stable are BNIs?
- Soil conditions influence on BNIs functioning
- BNI concentration required in soil to be effective
- Effectiveness in tropics vs temperature environs
- Regulatory mechanisms for BNI release
- Mode of inhibitory action
- Negative effects on soil microbial community
BNI activity added to the soil (AT g^{-1} soil)

Releases about 200 to 400 ATU hydrophilic BNI d^{-1}

Release rates  
Stability  
ED_{50}  
Determines

Effectiveness of BNI function in the field

BNI s can provide stable inhibitory effect on soil nitrification
Plants produce a cocktail of BNIs to suppress nitrifying bacteria *Nitrosomonas*

BNIs isolated from sorghum
- Methyl 3-(4-hydroxyphenyl)propionate
  - Root exudate
- Sorgoleone
  - Root exudate
- Sakuranetin
  - Root exudate

BNIs isolated from *B. humidicola*
- Methyl p-coumarate
  - Root tissue
- Methyl ferulate
  - Root tissue
- Brachialactone
  - Root exudate
- α-linoleic acid
  - Root tissue
- Linoleic acid
  - Root tissue

AMO blocker

AMO & HAO blocker

ET disruptor
How much BNI-activity is released from root systems of *B. humidicola*?

**An assessment**

*B. humidicola* roots can release 2.6 to 7.5 million BNI activity d⁻¹ ha⁻¹

- **Active root biomass in a long-term BH pasture being 1.5 Mg ha⁻¹**
  - (Root mass up to 9.0 Mg ha⁻¹ has been reported in BH pastures)
  - BNI release rates can be 17 to 50 ATU g⁻¹ root dry wt. d⁻¹

- Estimated BNI activity release d⁻¹ could be 2.6 x 10⁶ to 7.5 x 10⁶ ATU
  
  (CIAT 679)  (CIAT 26159)

- 1 ATU being equal to 0.6 µg of nitrapyrin

- This amounts to an inhibitory potential equivalent to the application of 6.2 to 18 kg of nitrapyrin application ha⁻¹ yr⁻¹

Does it work in the field?
Can we breed for high-BNI capacity in food- and feed crops? Developing low-nitrifying and low-N2O emitting systems

Brachiaria pastures suppressed N2O emissions from the field
Can BNI function in plants be exploited to develop low-N2O emitting systems then?

Cumulative N2O emissions (mg of N2O N per m² per year) from field plots of tropical pasture grasses
(monitored monthly over a 3-year period, from September 2004 to November 2007)

©2009 by National Academy of Sciences
Subbarao G V et al. PNAS 2009;106:17302-17307
Nitrogen excreted (from urine) from grazing animals from managed grasslands (9 million km²) is estimated at

>120 Tg N y⁻¹

Can BNI-enabled pastures help reducing $N_2O$ emissions from these grazing systems?

1800 million livestock units; 182 to 392 g N excreted per animal d⁻¹

Equal to synthetic Nitrogen fertilizer to global agricultural systems

Source: Saggar et al. 2005
Developing BNI-enabled crop/pasture varieties?

Sorghum-BNI characterization at a field site in ICRISAT, India
Sorgoleone phenotyping of mini-core sorghum germplasm (231 lines) - 2015

Breeding for high-sorgoleone producing sorghum cultivars - Feasible?

Highest sorgoleone producing germplasm

Germplasm line

Collected from Niger, WA

Sorgoleone released (µg plant⁻¹)

Mini-core Sorghum germplasm lines
Sorgoleone additions to the soil suppressed N₂O emissions

High-sorgoleone producing genetic stocks suppress N₂O emissions better than low-sorgoleone producing genetic stocks?

**Integrated N₂O emission**

- 200N
- 200N+Sorgoleone
- 200N+DCD

BNI-Mitigation Technology

- BNI: Biological Nitrification Inhibition
High sorgoleone producing sorghum genetic stocks have low N$_2$O emissions?

_Breeding for high-sorgoleone production could a proxy to develop low-N$_2$O emitting sorghum cultivars?

High-sorgoleone germplasm line has 50% lower N$_2$O emissions compared to low-sorgoleone producing germplasm.
**Wild-wheat has high-BNI capacity**

*Nobeoka Chinese Spring*  
*L. racemosus*  

Wild-wheat has high-BNI capacity, as seen in the graph below. The BNI activity released from the roots of *L. racemosus* is significantly higher compared to *Nobeoka* and *Chinese Spring*.

**Leymus** does not release BNI when grown with NO$_3$-N where pH of RE-collection solution will be of >6.0.

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**JIRCAS-CIMMYT partnership**

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**BNI-Mitigation Technology**

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**Leymus racemosus**
Benefits from Genetic-Mitigation using BNI - Technology

- Cost effective and Scalable
- Delivery of BNIs - precise and effective
- Cocktail of inhibitors from BNIs – more stable effect
- No negative environmental consequences
- No health issues on food or feed quality
- Improve soil-N-retention and fertility
Portfolio of current technologies to reduce nitrification and N₂O emissions

- Synthetic nitrification inhibitors
- Urease inhibitors
- Slow-release nitrogen fertilizers
- Polythene-coated nitrogen fertilizers
- Split-Nitrogen applications
- Precision farming – ‘Green-seeker’ technology
- AWD (alternate wetting and drying) for paddy rice systems

BNI-technology could become part of portfolio of technologies to address GHG emissions from agriculture
Developing novel Mitigation-technologies
critical to reduce GHG emissions from agriculture

Paris Climate Agreement signed in 2015 calls to hold the global average temperature to <2°C above preindustrial levels by for 80% reduction in GHG emissions from current levels by 2050

With substantial mitigation

Without additional mitigation

Change in average surface temperature (1986–2005 to 2081–2100)

Source: IPCC AR5 synthesis report

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“...holding the increase in the global average temperature to well below 2 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C”
The smart way to address climate change is through **Innovation**

**Energy Production and Transport Sectors**

Solar-electricity, Hybrid Cars, Electric cars are some of the GHG reducing technologies emerged recently

Reducing GHG emissions from Agriculture reduces N-pollution, N-fertilizer consumption, improve soil fertility and sustainability of production systems

*Low N\textsubscript{2}O emission systems are a ‘WIN WIN’ situation for both environment and for Agriculture*

**Funding support for BNI Research**

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- CRP-WHEAT
- JIRCAS-President’s special grants
- JSPS Research Grants
Arctic is melting fast
Time for action
from Agricultural Scientific Community

Huge waterfall spouting from the ice edge of Brasvell Glacier – Getty image

Thank You for the attention