Methane emissions from rice cultivation:
IRRI’s mitigation options

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Outline of Presentation

- Significance of CH$_4$ emissions on Climate Change
- CH$_4$ emissions from rice cultivation
- Mitigation strategies
There are many uncertainties about the future climate,

BUT

two universal trends are predicted by most climate change models:

**(1) Temperatures will increase**
- more heat stress
- Sea level rise (thermal expansion of water and melting of ice)

**(2) More frequent and severe climate extremes**
- more floods
- more droughts

(Source: EPA website)
Climate Change will Aggravate the Abiotic Stresses in Rice!

(1) **Heat stress**

- extreme heat episodes can irreversibly damage rice yield, grain quality, germination and fertilization
- heat stress during flowering – complete sterility
- heat stress during ripening – reduced grain filling & poor milling quality (more broken grains)

What would be the impacts of Climate Change on rice?

- Due to climate change, the number of hot days and warm nights have increased
- higher nighttime temp – reduced yields by as much as 10% for every 1°C increase in minimum temp due to increase in respiration (Peng et al., 2004)
Climate Change will Aggravate the Abiotic Stresses in Rice!

(2) Drought or water stress

- most widespread and damaging of all abiotic stresses
- major source of yield & economic loss in rice production
- affects all stages of rice growth and development
- the strong effects of drought on grain yield are largely due to the reduction of spikelet fertility and panicle exsertion

- With the onset of climate change, the intensity and frequency of droughts are predicted to increase in rainfed rice-growing areas and droughts could extend further into water-short irrigated areas
Climate Change will Aggravate the Abiotic Stresses in Rice!

(3) Salinity

- NaCl – major salt that causes this problem
- rice is highly sensitive to salt stress in its early growth stage and a few days before panicle initiation to flowering stage
- ECe 3 dS/m – salinity threshold for rice

- When sea level rises due to climate change, saline water will be brought inland and expose more rice growing areas in the low-lying deltas and coastal areas to salty conditions
Climate Change will Aggravate the Abiotic Stresses in Rice!

(4) Submergence/ Flooding

- Submergence either short-term (flash floods) or long-term (stagnant flooding) can affect rice crops at any stage of growth.
- The chances of survival are extremely low when completely submerged during the crop’s vegetative stage.

- With climate change, major flooding events are likely to increase in frequency caused by sea level rise in coastal areas and the predicted increased intensity of tropical storms.

Mega deltas in Asia are most vulnerable
Contribution of rice production to greenhouse gas effect

Nitrous oxide (N₂O)

Inorganic fertilizers

Flooding creates anaerobic conditions

Methane (CH₄)

Organic Material (e.g., Rice straw, etc.)

25X

300X
Why is methane important?

Radiative forcing: CO$_2$ (~60%), CH$_4$ (~20%)  
(Forster et al., 2007)

CH$_4$ GWP: 25 (100-yr time horizon)  
(Forster et al., 2007)

CH$_4$ concentration: 0.7 to 1.80 ppm V  
(Hartmann et al., 2013)

Total global CH$_4$ budget: 500-600 Tg CH$_4$ yr$^{-1}$  
(Dlugokencky et al., 2011)

Residence time: CH$_4$ (~9 yrs), CO$_2$ (~100 yrs), N$_2$O (~170 yrs)

Because CH$_4$ is both a powerful GHG and short-lived compared to CO$_2$, achieving significant reductions would have a rapid and significant effect on atmospheric warming potential.
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Baseline Methane Research

Interregional Program on Methane Emissions from Rice Fields
(funded by UNDP/GEF, 1993-1999)
Rice ecosystems in Asia

CH$_4$ emissions from different rice fields:
irrigated rice $\geq$ continuously flooded rice $>$
flood prone rainfed rice $\geq$ deepwater rice $>$
drought prone rainfed rice $>$ tidal rice
Methane emissions from rice paddy

About 75% of our global rice production comes from irrigated rice-based cropping systems

(FAOSTAT, 2015)
Rice is the staple food of more than 50% of the world's population. 90% of world's rice is grown and consumed in Asia (UN, 2015).
Methane in paddy fields

Pools: entrapped CH₄, dissolved CH₄ in soil solution

Fluxes: plant-mediated, ebullition, diffusion

Flooding creates anaerobic condition

Methane oxidation:
\[ CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \]

Methanogenesis:
- Hydrogenotrophic: \[ CO_2 + 4H_2 \rightarrow 2H_2O + CH_4 \]
- Acetotrophic: \[ CH_3COOH \rightarrow CO_2 + CH_4 \]
Factors affecting CH$_4$ emissions in paddy fields

- Flooding (Eh < -150 mv)
- Organic substrate (straw residues, green manure, animal manure)
- Soil type (heavy clay soils)
- Soil temperature (35°C)
- Soil pH 6.4 to 7.8
- Tillage
- Rice cultivar
- Fertilizers containing nitrates and sulfates inhibit CH$_4$ production

Flooding creates anaerobic conditions
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Mitigation options

- water-saving practices
  - mid-season drainage
  - intermittent irrigation
  - safe alternate wetting and drying (AWD)
- efficient nutrient management
- smart management of rice residues
Safe alternate wetting and drying (AWD)

• Start AWD at 10 DAT with 5-cm floodwater
• Irrigate when water is 15-cm below soil surface
• Keep 5-cm floodwater at flowering (one week before and one week after)

• Save water: 15-30% less irrigation water
• Maintain yield: No yield penalty
• Increase water productivity
• Increase profit in deep well and shallow tube well systems

• Message for farmers: ‘Water is there even when you can’t see it’
AWD reduces GWP contribution of N₂O and CH₄

- AWD decreased CH₄ emissions by 60–90% during the DS compared with continuous flooding (CF) (Hosen et al., 2010)

- N topdressing immediately before or after irrigation (AWD 2) decreased N₂O emissions by 80% compared with N topdressing 2 days before irrigation (AWD 1)

- When the field was kept flooded for a week after N topdressing (AWD 3), N₂O emission decreased similar to CF
Promoting AWD

Overview of AWD

IRRI has been promoting AWD as a smart water-saving method that reduces GHG emissions from irrigated rice. Through the national agricultural research and extension systems (NARES), farmers are being trained and the use of AWD are being promoted in Bangladesh, the Philippines, and Vietnam.
AWD is part of the Palay Check System (Philippines)
AWD is directly mentioned as one mitigation option by the Ministry of Agriculture of Vietnam.

Farmers should use/apply AWD irrigation technology to not only greatly save water consumption and reduce GHGs emissions in irrigated rice fields, but also increase rice productivity.
CCAC Paddy Rice Component:

**Implementing Partners**: IRRI in Asia and CIAT in Latin America (with support from CCAFS)

**First-Mover Countries (Partner Countries for Implementation)**:

- Viet Nam
- Bangladesh
- Colombia

**Goal**: To disseminate alternate wetting and drying (AWD) on large scale to facilitate both, more stable food supply and reduction in methane emissions.
Efficient Nutrient Management

- Rice Crop Manager is a computer and mobile phone-based application
- provides farmers with site- and season-specific recommendations for fertilization
- allows farmers to adjust nutrient application to crop needs in a given location and season
Smart management of rice straw residues

Partial aerobic decomposition of residues under dry fallow condition

Shallow tillage of residues immediately after harvest
Impact of straw incorporation & water management during fallow and growing periods on reduction in CH₄ emissions

<table>
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<tr>
<th>Reference</th>
<th>Year/Season</th>
<th>Straw Residue</th>
<th>Fallow period</th>
<th>Growing period</th>
<th>CH₄ emission (kg CH₄ ha⁻¹)</th>
<th>% CH₄ reduction</th>
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<td>Wassmann et al., 1996</td>
<td>1992 WS</td>
<td>incorporated</td>
<td>Flooded</td>
<td>Flooded</td>
<td>193 ± 41</td>
<td>(reference)</td>
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<td>1993 DS</td>
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<tr>
<td>Alberto et al., 2015</td>
<td>2013 WS</td>
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<td>Dry</td>
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<td>106 ± 20</td>
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<tr>
<td>Alberto et al., 2015</td>
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<td>Dry</td>
<td>Intermittent AWD</td>
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Smart management of rice straw residues

Shallow tillage of residues immediately after harvest

Use biochar instead of fresh rice straw

Partial aerobic decomposition of residues under dry fallow condition
Innovative handling and uses of rice straw and rice husks
Key Messages
(Richards and Sander, 2014)

- Flooded rice produces approximately 20-40 Mt of CH₄ per year, or about 10-12% of the anthropogenic emissions from the agriculture sector globally.
- Alternate wetting and drying (AWD) is a rice management practice that reduces water use by up to 30% and can save farmers money on irrigation and pumping costs.
- AWD reduces methane emissions by 48% without reducing yield.
- Efficient nitrogen use and application of organic inputs to dry soil can further reduce methane emissions.
"It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change."

Charles Darwin
Two approaches

- **Mitigation**: develop new technologies that can reduce greenhouse gas emissions and increase the C sequestration in biomass and soil (reduce the C footprint)

- **Adaptation**: development of rice plants and crop management to withstand extreme climate and to make rice-cropping systems more resilient
Adaptation strategies

- developing climate-proof rice varieties
- crop diversification
- crop intensification
- decision support systems
Making rice climate-proof

drought

salinity

submergence

heat
Shifting from traditional rice cultivation to crop diversification and intensification

**Block UY**
- Rice: 7 t/ha
- Rice: 4.5 t/ha

**Block UE**
- Dry seeded rice: 6 t/ha
- Mungbean: 1.2 t/ha
- Rice: 4.5 t/ha

**Block UJ**
- Maize: 11 t/ha
- Dry seeded rice: 5 t/ha
- Rice: 4.5 t/ha
WeRise (weather-rice-nutrient integrated decision support system)

- WeRise provides complimentary information to existing systems
- WeRise can describe the characteristics of upcoming rainy season (start/end of season, distribution of rainfall, flood/drought occurrences) and can predict GY of farmers’ preferred varieties as a function of sowing date, timing of appropriate fertilizer application at crucial crop growth stages

Available information from WeRise

- Weather advisory
  - Weather prediction (10 days)
  - Observed vs. WeRise Prediction
  - On-site evaluation (Weather)
    - Rainfall
    - Temp max
    - Temp min
    - Vapor pressure

- Grain yield advisory
  - GY prediction at different sowing dates
  - Optimal fertilizer application timings
  - On-site evaluation (GY)
    - Sowing date
    - GY (kg/ha)
    - Variety: IR64
    - Location: C Java

- On-site evaluation (WeRise Field testing)
- Farmers’ practice
- WeRise prediction

http://irri.org/tools-and-databases/swerise
Operation of Mobile Phone App

Cloud based server

Rice Crop Manager
- Nutrients
- Weeds
- Irrigation
- ....

New Modules
- GHG emission calculator
- Climate-adjusted yield targets

Climate-Informed Rice Crop and Low Emission Manager
=> CIRCLE Manager

Obtain site-specific information from farmer/operator

Provide management recommendation
Climate Change Attribution

The Greenhouse Effect

Some sunlight that hits the earth is reflected. Some becomes heat.

CO₂ and other gases in the atmosphere trap heat, keeping the earth warm.