Development of FBMPs: Global Experience

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Context Setting
Global Population Trends and Predictions

POPULATION OF THE EARTH
Between 1 billion to 2 billion = 123 years
Between 2 billion to 3 billion = 33 years
Additional billions added in 12-14 years
Between 2000 and 2050, the increase of 3 billion in population will come from:
Asia – 1.5 billion (40% increase)
Africa – 1.0 billion (doubling)

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Secured Access to Food in an Ecologically Sustainable Manner is a Continuing Challenge

- “The seriousness or magnitude of the world food problem should not be underestimated. Recent success in expanding wheat, rice and maize production in Asian countries offers the possibility of buying 20-30 years of time.” Dr. Norman Borlaugh, 1969

- “The next few decades present a greater challenge to the world food systems than they may ever face again. The effort needed to increase production in pace with an unprecedented increase in demand, while retaining the essential ecological integrity of food systems, is colossal both in its magnitude and complexity. Given the obstacles to be overcome, most of them man-made, it can fail more easily than it can succeed.”……Advisory Panel on Food Security, Agriculture, Forestry, and Environment. 1987
Brundtland’s report


**Definition**
Accommodating the growing demand for production without compromising the natural resources upon which agriculture depends.

The concept of sustainability is multidimensional ... applies to social, economic, and environmental dimensions simultaneously.


**Relationship between Fertilizer use and cereal productivity – Global scenario**

\[ R^2 = 0.3264 \]

Source: FAOSTat and IFA’s “Assessment of Fertilizer Use by Crop at the Global Level 2010-2011” Report
Cropland Management Measures to Help Mitigate GHGs

- Cropland management, which includes nutrient management, has a GHG mitigation potential approaching 1,600 MT CO$_2$-equivalent/yr

<table>
<thead>
<tr>
<th>Examples</th>
<th>Mitigative effects$^a$</th>
<th>Net mitigation$^b$ (confidence)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomy</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>Nutrient management</td>
<td>+</td>
<td>***</td>
</tr>
<tr>
<td>Tillage/residue management</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>Water management (irrigation, drainage)</td>
<td>+/-</td>
<td>***</td>
</tr>
<tr>
<td>Rice management</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>Agro-forestry</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>Set-aside, land-use change</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Smith et al. 2007. Agriculture. In Climate Change 2007: Mitigation. IPCC

Soil Quality Change (as % over Fallow) under Different Management Practices & Cropping Systems

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rice-Wheat</th>
<th>Rice-Lentil</th>
<th>Jute-Rice-Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-56.0</td>
<td>-8.0</td>
<td>-49.0</td>
</tr>
<tr>
<td>N-only</td>
<td>-</td>
<td>-11.7</td>
<td>-35.0</td>
</tr>
<tr>
<td>NPK-only</td>
<td>-10.8</td>
<td>-9.7</td>
<td>19.0</td>
</tr>
<tr>
<td>NPK+FYM</td>
<td>18.7</td>
<td>8.6</td>
<td>45.1</td>
</tr>
</tbody>
</table>

Fertilizer Best Management Practices (FBMP)

What is FBMP

Fertilizer best management practices (FBMPs) are agricultural production techniques and practices developed through scientific researches and verified in farmers fields to maximize economic, social and environmental benefits.

FBMP is aimed at managing the flow of nutrients in the course of producing affordable and healthy food in a sustainable manner that protect the environment and conserve natural resources at the same time profitable to producers.

With FBMPs, farmers implement, under specific site, crop and soil conditions, the concepts and elements of balanced fertilization, site-specific nutrient management (SSNM), integrated plant nutrient management (IPNM), among others.
BMP adoption and evaluation – farm level

- Adaptive management

Farm Level
Producers, Crop advisers

DECISION
Accept, revise, or reject

ACTION
Change in practice

EVALUATION of OUTCOME
Cropping System Sustainability Performance

LOCAL SITE FACTORS
- Climate
- Policies
- Land Tenure
- Technologies
- Financing
- Prices
- Logistics
- Management
- Weather
- Soil
- Crop demand
- Potential losses
- Ecosystem vulnerability

BMP adoption and evaluation – regional level

- Logistics and science

Regional Level
Agronomic Scientists, Agri-service Providers

DECISION SUPPORT based on scientific principles

OUTPUT
Recommendation of right source, rate, time, and place (BMPs)

Farm Level
Producers, Crop advisers

DECISION
Accept, revise, or reject

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- Soil
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- Potential losses
- Ecosystem vulnerability
BMP adoption and evaluation – policy level

- Infrastructure and incentive

**Policy Level** – Regulatory, Infrastructure, Product Development

**Regional Level** - Agronomic Scientists, Agri-service Providers

**Farm Level** - Producers, Crop advisers

**DECISION SUPPORT** based on scientific principles

**OUTPUT**
- Recommendation of right source, rate, time, and place (BMPs)

**DECISION**
- Accept, revise, or reject

**ACTION**
- Change in practice

**EVALUATION of OUTCOME**
- Cropping System Sustainability Performance

**LOCAL SITE FACTORS**
- Climate
- Policies
- Land Tenure
- Technologies
- Financing
- Prices
- Logistics
- Management
- Weather
- Soil
- Crop demand
- Potential losses
- Ecosystem vulnerability

**FBMP Focus**

- USDA-ARS – Best management practices include soil and water conservation practices, other management techniques, and social actions that are developed for a particular region as effective and practical tools for environmental protection

- FDCO and FAO – A set of agronomic and other soil-crop management practices, which lead to the best possible use of applied inputs for crop production, resulting in minimal adverse effect on the environment. A pre-requisite for efficient and environment-friendly fertilizer use. Important for all soils, crops and fertilizers

- BMP Challenge – BMPs are designed to save you money by using your field history and soil test results to cut fertilizer costs and maintain yield

- North Carolina State University – Farming methods that assure optimum plant growth and minimize adverse environmental effects

- PPI – Practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency and environmental protection.
Why do we need FBMP

Improving Crop Productivity in a Sustainable Manner

Climate X Genetics X Management

- Better Genetics
- Better Management
  - Water Management
  - Nutrient Management (FBMP)
  - Pest & Disease Management
Long term: Breeding & Biotechnology  
Immediate, medium term: Agronomic management  
Policy support  
Business as usual/Existing knowledge  
Improved Agronomic management  
Breeding/strains  
Genetic Engg/Biotech  

Productivity & efficiency of inputs  
Timeline  

Management Yield Gaps  
Rice 51%  
Wheat 36%  
Maize 66%  

Potential Yield Gaps  
Rice 62%  
Wheat 48%  
Maize 74%  

Productivity with Efficiency: Where Will Future Gains Come From?

FBMPs are Critical in the Current Scenario

For sustainable access to food, crop production would have to increase on essentially the same land area, with less water, nutrients, fossil fuel, labor and as climate change

- Economic viability of farming  
  - Increasing input cost  
  - Unavailability of labor  
- Increasing environmental awareness

Food Security  
Economic Stability  
Environmental Sustainability

Effects are magnified in smallholder systems
Optimizing Nutrient Management in Rice-Wheat System (RWS): Yield and Efficiency Improvement

The average net return in OPT in the RWS was US$ 498.3 over FFP and US$ 276.2 over SR.

Average on-farm PFP\textsubscript{N} (kg grain/kg N); n=120:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Optimum Fertilization</th>
<th>State Recommendation</th>
<th>Farmers’ Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>54.5 (± 2.5)</td>
<td>45.8 (± 2.1)</td>
<td>39.4 (± 1.9)</td>
</tr>
<tr>
<td>Wheat</td>
<td>35.3 (± 1.3)</td>
<td>29.8 (± 0.9)</td>
<td>25.3 (± 0.6)</td>
</tr>
</tbody>
</table>

Source: Singh et al., 2014. Field Crops Res. 164: 30–44

Environmental footprints of fertilizer NPK production in India - Trends

Source: Jat et al (2014), based on IPCC protocols
Inappropriate fertilizer use a growing challenge in India

- Environmental Impacts:
  - It is estimated that 80% of N$_2$O emissions come from agriculture and burning in India
  - With crop N recovery estimated at 33-50%, unused N in soils can impact the environment
  - P losses in soil runoff, especially where fertilizer is surface applied
- Agricultural Impacts:
  - Nutrient mining of soils….severe depletion in many instances affecting crop productivity
  - Nutrient losses lead to lower NUE, lost profit
  - Nutrient losses lead to lower quality product, lost profit

In India, adverse impacts are more commonly associated with unbalanced use, rather than overuse

4R Nutrient Stewardship
Source, Rate, Time, and Place describe any nutrient application

4R Nutrient Stewardship — applying the right nutrient source, at the right rate, right time, and right place — is an essential tool in the development of sustainable agricultural systems.

- Implementation of 4R Nutrient Stewardship can positively influence the sustainability of agricultural systems beyond the immediate benefits of improved crop nutrition and production.
4R: Science-based Practical Choices to Implement FBMPs

Examples of key scientific principles

<table>
<thead>
<tr>
<th>Key Scientific Principles</th>
<th>Source</th>
<th>Rate</th>
<th>Time</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ensure balanced supply of nutrients</td>
<td>• Test soils for nutrients</td>
<td>• Pre-plant</td>
<td>• Broadcast</td>
<td></td>
</tr>
<tr>
<td>• Suit soil properties</td>
<td>• Calculate economics</td>
<td>• At planting</td>
<td>• Band/drill/inject</td>
<td></td>
</tr>
</tbody>
</table>

Examples of practical choices

<table>
<thead>
<tr>
<th>Source</th>
<th>Rate</th>
<th>Time</th>
<th>Place</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Commercial fertilizer</td>
<td>• Test soils for nutrients</td>
<td>• Pre-plant</td>
<td>• Broadcast</td>
</tr>
<tr>
<td>• Livestock manure</td>
<td>• Calculate economics</td>
<td>• At planting</td>
<td>• Band/drill/inject</td>
</tr>
<tr>
<td>• Compost</td>
<td>• Balance crop removal</td>
<td>• At flowering</td>
<td>• Variable-rate application</td>
</tr>
<tr>
<td>• Crop Residue</td>
<td></td>
<td>• At fruting</td>
<td></td>
</tr>
</tbody>
</table>

What is the Connect between FBMP & 4R

Concept

Fertilizer Best Management Practices

Application

4R Nutrient Stewardship Principles

Outcome

Social, Economic, and Environmental benefits to the Society
4R Interventions

Expected Outcome from Application of 4R

- Maintain or improve crop productivity
  - Appropriate nutrient management for
    - nutrient acquisition efficient cultivars
    - Drought, flood and heat resistant cultivars
  - Crop Management
    - Manage abiotic and biotic stresses
    - Provide adequate and balanced plant nutrition
    - Soil fertility depletion

- Reduce environmental footprints of plant nutrients
  - GHG emission
  - Eutrophication

- Convergence of scale-neutral technologies to achieve the above goals
  - Farm size
  - Farmer resources
Source-Effect of N fertilizer Source on $\text{N}_2\text{O}$ Emission from Semi-arid, irrigated Maize

Nitrogen sources compared to the commonly used granular urea (46% N) and liquid UAN (32% N) included a controlled-release polymer-coated urea (ESN®), stabilized urea and UAN products containing nitrification and urease inhibitors (SuperU and UAN-Agrotran/Ptaff), and UAN containing a slow release N source (Nfusion®). A subsurface band ESN treatment (ESNsub) was also included.

Halvorson and Del Grosso, Better Crops/Vol. 96 (2012, No. 4), pp. 7-9

4R - Source X Place
Reduction in N loss through proper placement in Maize

Lara-Cabezas et al. 1997
**4R – Time:** Effect of N Application time on Yield and Agronomic Efficiency of Irrigated Maize

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Maize Grain Yield Mg ha(^{-1}) and AE (kg kg(^{-1}))</th>
<th>Maros (Indonesia)</th>
<th>O Mon (Vietnam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2008</td>
<td>2009</td>
</tr>
<tr>
<td>2-Split Fixed Rate</td>
<td></td>
<td>11.2 (58.7)</td>
<td>10.6 (46.8)</td>
</tr>
<tr>
<td>3-Split Fixed Rate</td>
<td></td>
<td>11.4 (62.8)</td>
<td>10.5 (45.8)</td>
</tr>
<tr>
<td>3-Split LCC1</td>
<td></td>
<td>12.3 (64.8)</td>
<td>11.1 (47.0)</td>
</tr>
<tr>
<td>3-Split LCC2</td>
<td></td>
<td>12.6 (65.7)</td>
<td>12.1 (46.4)</td>
</tr>
</tbody>
</table>

1.0 t/ha from increased split and use of LCC


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**4R-Rate X Time:** GreenSeeker based N application in rice

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>N Management Strategy</th>
<th>Total N applied (kg/ha)</th>
<th>Rice grain yield (kg/ha)</th>
<th>Total N Uptake (kg/ha)</th>
<th>AE(_N) (kg/kg)</th>
<th>RE(_N) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAU 201</td>
<td>No N</td>
<td>0</td>
<td>3.99</td>
<td>57.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Three equal splits</td>
<td>120</td>
<td>6.96</td>
<td>131.7</td>
<td>24.7</td>
<td>61.6</td>
</tr>
<tr>
<td></td>
<td>GreenSeeker-based</td>
<td>102</td>
<td>7.16</td>
<td>130.8</td>
<td>31.0</td>
<td>71.5</td>
</tr>
<tr>
<td>PUSA 44</td>
<td>No N</td>
<td>0</td>
<td>3.94</td>
<td>63.1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Three equal splits</td>
<td>120</td>
<td>6.38</td>
<td>121.6</td>
<td>20.3</td>
<td>48.7</td>
</tr>
<tr>
<td></td>
<td>GreenSeeker-based</td>
<td>97</td>
<td>6.37</td>
<td>117.0</td>
<td>25.1</td>
<td>55.6</td>
</tr>
<tr>
<td>HKR 127</td>
<td>No N</td>
<td>0</td>
<td>3.75</td>
<td>57.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Three equal splits</td>
<td>120</td>
<td>6.04</td>
<td>120.4</td>
<td>19.1</td>
<td>52.1</td>
</tr>
<tr>
<td></td>
<td>GreenSeeker-based</td>
<td>102</td>
<td>6.19</td>
<td>117.7</td>
<td>23.8</td>
<td>58.6</td>
</tr>
</tbody>
</table>

Bijay-Singh et al., 2015
## 4R – Source X Rate X Time: Nutrient Expert® (NE) for Maize in India, Indonesia, and Philippines (2010-14)

**Current situation: Farmers' yield < attainable yield**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Effect of NE (NE – FFP)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>India (n = 412)</td>
<td>Indonesia (n = 26)</td>
</tr>
<tr>
<td>Grain yield</td>
<td>t/ha</td>
<td>+1.27 ***</td>
<td>+0.92 ***</td>
</tr>
<tr>
<td>Fertilizer N</td>
<td>kg/ha</td>
<td>−6 ns</td>
<td>−12 ns</td>
</tr>
<tr>
<td>Fertilizer P$_2$O$_5$</td>
<td>kg/ha</td>
<td>−16 ***</td>
<td>−5 ns</td>
</tr>
<tr>
<td>Fertilizer K$_2$O</td>
<td>kg/ha</td>
<td>+22 ***</td>
<td>+15 ***</td>
</tr>
<tr>
<td>Fertilizer cost</td>
<td>USD/ha</td>
<td>−1 ns</td>
<td>+16 ns</td>
</tr>
<tr>
<td>Gross profit</td>
<td>USD/ha</td>
<td>+256 ***</td>
<td>+234 ***</td>
</tr>
</tbody>
</table>

*** significant at P<0.001; ns = not significant

## 4R – Source X Rate X Time: Nutrient Expert® in China (2010-13)

**Current situation: Farmers' yield = attainable yield**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Wheat (n = 290)</th>
<th>Maize (n = 541)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>FP</td>
<td>NE</td>
</tr>
<tr>
<td>Grain yield</td>
<td>t/ha</td>
<td>7.9</td>
<td>8.0</td>
</tr>
<tr>
<td>N</td>
<td>kg/ha</td>
<td>271</td>
<td>162</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>kg/ha</td>
<td>118</td>
<td>82</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>kg/ha</td>
<td>50</td>
<td>74</td>
</tr>
<tr>
<td>Fert. cost</td>
<td>USD/ha</td>
<td>357</td>
<td>267</td>
</tr>
<tr>
<td>Gross profit</td>
<td>USD/ha</td>
<td>2282</td>
<td>2417</td>
</tr>
<tr>
<td>REN</td>
<td>%</td>
<td>17.5</td>
<td>30.2</td>
</tr>
<tr>
<td>AEN</td>
<td>kg/kg</td>
<td>5.2</td>
<td>8.6</td>
</tr>
</tbody>
</table>

REN: apparent recovery efficiency of N (increase in N uptake/applied N)
AEN: agronomic efficiency of N (kg yield increase/kg applied N)
**4R – Source X Rate X Time:** Nutrient Expert® reduced GHG emission in wheat with increased yield and profit

Northwest India: 2010-12

Researchable Issues

Source: Sapkota et al. 2014, Field Crops Res. 155: 233-244
What are the Grey Areas

• Source
  – Conventional vs. Enhanced Efficiency Fertilizer
  – Commodity vs. Specialty Fertilizer

• Rate
  – Sole vs. Intercropping or Relay Cropping
  – When foliar application is part of the strategy
  – In high P fixing soils

• Time
  – Intercropping

• Place
  – Surface Application vs. Sub-surface Drilling vs. Fertigation at Root Zone

What are the Grey Areas

• 4Rs for Cropping systems
  – Individual Crop vs. Cropping System
  – When crops are grown in sequence under anaerobic and aerobic growing environment

• 4Rs under CA systems
  – Conventional vs. Zero-till crop establishment
  – Under differential residue retention

• 4Rs for Climate Change Adaptation/Mitigation
  – Drought
  – Excess precipitation
  – Heat stress
Conclusions

- World-wide increasing population needs sustainable access to food
- Fertilizer plays a critical role in ensuring food security
- **Fertilizer best management practices** (FBMPs) are agricultural production techniques and practices to give optimum production potential, input efficiency and environmental protection
- The 4R Nutrient Stewardship provides science-based practical choices for on-farm implementation of FBMPs
- Fine tuning of 4R strategies in specific crop growing environments and management practices are required through further research