Welcome!

Note: assigned seating before lunch! Your table # is on your name tag.
The Sustainable P Alliance is a members organization that exists to catalyze the implementation of technical, organizational, and institutional innovations to advance phosphorus sustainability in North America.
Who are we?

Leadership

Jim Elser
Director, Sustainable Phosphorus Alliance
Jim Elser is a limnologist with research focused on the effect of key limiting nutrients such as nitrogen and phosphorus in lake ecosystems. He is a Research Professor and Distinguished Sustainability Scientist in ASU's School of Life Sciences and School of Sustainability and serves as the Director for the Sustainable Phosphorus Alliance. He is also director of the Flathead Lake Biological Station of the University of Montana.

Matt Scholz
Program Manager, Sustainable Phosphorus Alliance
Matt Scholz is the Program Manager for the Sustainable Phosphorus Alliance. He worked for 3 years as a Senior Research Scientist for The Sustainability Consortium after completing a postdoc in the Department of Chemistry at Colorado School of Mines and a PhD at the University of Arizona, where his research focused on algal biofuels. He has worked in maize molecular genetics and holds an MS in environmental engineering from the University of Arizona.

Rebecca Muenich
Research Scientist, Sustainable Phosphorus Alliance
Rebecca Muenich is an environmental engineer with expertise in environmental modeling, especially in evaluating the impact of land management decisions on nutrient inputs into the environment. She recently completed a postdoctoral position at the University of Michigan where she focused on finding win-win solutions to address excess phosphorus inputs into Lake Erie. She is currently an Assistant Professor in ASU’s School of Sustainable Engineering and the Built Environment and serves as a Research Scientist with the Sustainable Phosphorus Alliance. She holds a BS in biological engineering from the University of Arkansas, and MS and PhD degrees in agricultural and biological engineering from Purdue University.

Board of Directors

Kerry McNamara
Executive Director, OCP Research LLC

Matt Nazma
Vice President, Ostara

Michael Schmid
Chief Marketing and Operations Office, Renewable Nutrients

Amol Prasad
Chief Innovation and Development Officer, The Water Research Foundation

Chris Hombach
Chief Technical Officer, National Association of Clean Water Agencies (NACWA)

Brian Madigan
Director of Business Development, FEEDCO International

Sustainable Phosphorus Alliance
Our Mission

Our mission is to be North America’s central forum and advocate for the sustainable use, recovery, and recycling of phosphorus in the food system.

Our Vision

We envision a food system that manages phosphorus more sustainably to provide abundant, nutritious food while protecting the health of rivers, lakes, and oceans.

<table>
<thead>
<tr>
<th>Objectivity</th>
<th>Stewardship</th>
<th>Inclusivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our decisions and actions are based in the best available science.</td>
<td>We support the implementation of technologies and practices that benefit ecosystems and not ones that facilitate their deterioration.</td>
<td>We seek buy-in from diverse stakeholders about best policies and practices.</td>
</tr>
</tbody>
</table>
What we do

▪ **Facilitate networking** among diverse players from across the phosphorus value chain via knowledge sharing events.
  ▫ Annual conference on phosphorus sustainability (Phosphorus Forum)
  ▫ Technical webinar series on current issues in P sustainability
  ▫ Quarterly newsletter, blog, and social media (twitter: @SustainP)
▪ **Orchestrate working groups**, including our just-launched Biosolids and Manure Task Force.
▪ **Provide technical input** on metrics development (e.g. TSC, WEF) and research prioritization (e.g. TWRF)
▪ **Represent the North American P-sustainability community** both within other N. American organizations and within the global collective of P-sustainability platforms (e.g. ESPP)
▪ **Offer a branding opportunity** to organizations working in the vanguard of phosphorus sustainability.
Current project: Biosolids and Manure Task Force

**Motivation**

- Desire to encourage *sustainable* reuse of organic residuals
- Regulatory complexity around land application of biosolids and manure
- Need to get stakeholders talking to each other

**First stage deliverables**

- White paper landscape analysis of regulations (May/June timeframe)
- Beta-version [ArcGIS](https://www.arcgis.com) tool (August)
- Webinar (August/September)

**Second stage deliverables**

- Additional data layers TBD
- Scenario development sessions (in planning)
The Phosphorus Challenge / The Phosphorus Opportunity

Photos: foundationfar.org, via @rww, The Detroit News
Can Planet Earth Feed 10 Billion People?

Humanity has 30 years to find out. *The Atlantic* (March 2018)

Charles Mann
Wizards vs Prophets

**Wizards**
- Abundance & opportunity
- Techno-fixes

**Prophets**
- Limits to growth (carrying capacity)
- Environmental consequences
- Harmony with natural processes
A question for today:

Are you a *wizard* or are you a *prophet*?
A question for today:

OR: are you a wizard prophet?
TODAY’S AGENDA

- 8:30: Dr. Jim Elser (ASU) Welcome and our job today.
- 8:45: Keynote: Dr. Sally Rockey (FFAR)
- 9:30: Dr. David Vaccari (Stevens Inst of Technology) “A Substance Flow Model for Global Phosphorus”
- 10:00: Coffee & networking
- 10:30: Dr. Luis Herrera (CINVESTAV), GMO technology for phosphite fertilizer use
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Dr Sally Rockey, Executive Director Foundation for Food and Agriculture Research (FFAR)

A distinguished career!

- NIH (Deputy Director for Extramural Research)
- USDA (Chief Information Officer)
- USDA (Cooperative State Research, Education, Extension Service)
- USDA extramural funding programs
- PhD (Entomology) from the Ohio State University
The Future of Agricultural Research
Sally Rockey, Executive Director
Foundation for Food and Agriculture Research
@FoundationFAR | @RockTalking

Phosphorus Forum 2018 | February 27, 2018
Human’s closest relationship with Earth is through agriculture.
Innovations that have “done the most to shape the nature of modern life”

Top 10: printing press, electricity, penicillin, semiconductor electronics, optical lenses, paper, internal combustion engine, vaccination, Internet, and steam engine

11. Nitrogen fixation, 1918: Fritz Haber wins a Nobel Prize for the ammonia-synthesis Martinus Beijerinck
13. Refrigeration, 1850s:
22. Green Revolution, mid-20th century: Norman Borlaug’s green revolution
30. Moldboard plow, 18th century
32. Cotton gin, 1793
33. Pasteurization, 1863
38. Scientific plant breeding, 1866: Gregor Mendel
50. Self-propelled Combine harvester, 1930s
Agriculture is the place to be these days in science!

- Importance of the issues
- Take fundamental knowledge almost immediately to application
- New technologies often apply directly to agriculture before any other sector
- Growing consumer interest in the food system
How quickly can science make a difference?

On average, public agricultural research undertaken today will begin to noticeably influence agricultural productivity in as little as 2 years and its impact could be felt for as long as 30 years.
More data generated in the past two years than in the entire history of the human race.

The pace of science continues to accelerate.

We must take advantage of this incredible time in science.
Sequencing DNA has become 1 billion times faster and cheaper in the past 25 years.
What does a billion times faster look like?
Only 125,000 times faster
What does a billion times faster look like?
Imagine a 3.7 mile commute

Home

1 hour walk

3.7 mph

Work
What does a billion times faster look like?

Imagine a 3.7 mile commute

Home

1 hour walk

3.7 mph

Pluto
Burgeoning Fields in Ag Research

Progress happens when our knowledge of how things work converges with technological advances to reveal new ways to approach problems!

- Phenomic/Genomic Associations
- Big Data – Digital Ag
- New Technologies (imaging, drones)
- Reducing Environmental Impacts
- Systems Analysis
- Improving Plant Efficiency
- Soil Health => Human Health

Pic by Neil Palmer (CIAT).
Scientific innovation is critical to meet the needs of a growing global population.

$9.7 billion is needed by 2050

Source: UDA ERS and ASTI, Organisation for Economic Cooperation and Development

The Challenge

Funding for Agricultural R&D

Constant 2011 PPP$, billions

10
9
8
7
6
5
4
3
2
1
0


China

Western Europe

Asia-Pacific, including Canada

United States

India

Brazil

Source: UDA ERS and ASTI, Organisation for Economic Cooperation and Development
Trends in R&D by Agency

In billions of constant FY 2015 dollars
Why is agricultural research funding not commensurate with its value in improving the quality of life?

“When it comes right down to it, food is practically the whole story every time.”

- Kurt Vonnegut, Galápagos
More food will be eaten in the next 50 years than in the past 7,000 years.

How will we feed 10 billion people when public investment in food and agriculture R&D is declining?
OUR VISION

We envision a world in which ever-innovating and collaborative science provides every person access to affordable, nutritious food grown on thriving farms.
FFAR Mission

We build unique partnerships to support innovative science addressing today’s food and agriculture challenges.
The FFAR Model

• Established with bipartisan congressional support in 2014 Farm Bill
• Creates novel research partnerships across the food and agriculture sector.
• Works nimbly to efficiently address emerging issues in food and agriculture.
• Leverages public dollars with private dollars to expand research impact.
• Fills research gaps to ensure great science supports thriving farms, reduces food insecurity, and supports better health.
The FFAR model leverages private funds for public good

Source: USDA ERS
Why Engage Industry?

Shift to private and proprietary R&D in agriculture means we must move together.
Figure out the Pre-Competitive Space

- *Pooling resources for public benefit.*
- *Accomplishing more, together.*
Pre-Competitive Space

Areas of business in which a firm feels comfortable against competitive pressures, on the basis of its cost advantage and/or technological leadership.

Areas of business in which a firm feels uncomfortable against unambitious relaxation, on the basis of its cost disadvantage and/or technological inferiority.
Pre-Competitive Space

Area of research where outcomes offer no particular advantage relative to peers and where there is potential to positively impact all parties.

Allows resources and data to be readily shared.
Public-Private Partnership Incentives

Private sector incentives:
• Corporate social responsibility
• Rapidly overcome obstacles to advancement
• Cost savings
• Direct access to fundamental research
• Access to academic expertise
• Cultivate future employees

Public Sector incentives:
• Address real-world problems
• Transfer research quickly to the economy
• Access to resources and data otherwise unattainable
• Access to expertise
How to Make Public-Private Partnerships Work

- Shared Goals and Values (honesty)
- Agreement on responsibilities and rules of engagement (including IP)
- Transparent value proposition for each partner (trust)
- Synergy (goals cannot be achieved by any partner working alone)
- Skin-in-the-game from all partners
- Joint celebration of successes
- Shared responsibility for failures
Who is Funding Ag Research?

Investments are coming from unconventional sources

- Venture Capitalists
- Philanthropists
- Private Foundations
- Industry
  - Including non-ag companies
Grand Challenges in Agriculture

Feeding the World
Sustainable Livestock

Environmental Stewardship

Plant Efficiency

Improving Health & Nutrition

Icons by Alena Artemova, Atif Arshad, IconTrack, & Dream Icons via NounProject.com
March 1 Seeding Solutions opens for applications.
FFAR Funding in potential areas of interest to the Sustainable Phosphorus Alliance
“The nation that destroys its soil destroys itself.”

-Franklin D. Roosevelt
Soil Health

• Nutrient management
  • Seeding Solutions grant for 4R Nutrient research

• National Cover Crop Initiative
  • FFAR provided $2.2 million in funding to the Noble Research Institute for cover crop research.

• Soil Health Initiative
  • FFAR provided $9.4 to Soil Health Institute, Soil Health Partnership, and The Nature Conservancy to collaborate on soil health measurement project.
Doubling photosynthetic efficiency can increase yields up to 40%.

- Phenotype/genotype
  - Environmental resilience
  - Desired nutritional traits
- Taking advantage of the latest technologies – gene editing
Agricultural Water Use

- Irrigation technology innovations
- Reuse and recycling
- Water use efficiency
  - FFAR awarded a New Innovator Award to develop water use models to increase efficiency in the Corn Belt.
Sustainable Livestock Production

- Manure and runoff management
- Integrated livestock and crop production systems
  - FFAR Seeding Solutions grant to study integrated system for cattle and crops
Environmental Stewardship

• Research into reducing the environmental impact of agriculture

• WWF Food Waste Project
  • FFAR awarded $650,000 for research on reducing farm-level food losses.
  • This project will reduce stressors on the environment and ensure that the resources used to produce food don’t go to waste.
Partnerships
Advancing solutions to complex problems – TOGETHER

- COMPLEX PROBLEMS
- COLLABORATION
  - POOLED RESOURCES
  - POOLED KNOWLEDGE
  - SHARED RISK
- CHANGE TO BENEFIT HUMANITY
Let’s work together to support and apply agriculture research that spurs the innovation we need for human, environmental and economic health in the future.

Connect with FFAR

Text FFAR to 22828 or visit http://bit.ly/ffarnewsletter
Thank You

Dr. Sally Rockey
Executive Director
Foundation for Food and Agriculture Research
srockey@foundationfar.org
@RockTalking

Connect with FFAR
www.foundationfar.org
@FoundationFAR
Phosphorus Forum 2018

February 27, 2018 | Tempe, AZ

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phosphorusalliance.org/events
#Phorum18
A Substance Flow Model for Global Phosphorus

Sustainable Phosphorus Alliance

David A. Vaccari, Stephen Powers, Xin Liu, Tom Bruulsema
Global Trend in Production and Population

![Graph showing the trend of production and world population over time. The graph includes data points and a line indicating the growth.](image-url)
Per Capita Global PR Production

<table>
<thead>
<tr>
<th>Year</th>
<th>Kg PR/cap/yr</th>
<th>g P/cap/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg 1974-1990</td>
<td>30.1</td>
<td>10.8</td>
</tr>
<tr>
<td>Avg 1993-2008</td>
<td>22.7</td>
<td>8.15</td>
</tr>
<tr>
<td>2017</td>
<td>35.5</td>
<td>12.7</td>
</tr>
</tbody>
</table>
Trend in U.S. Production and Exports
## The Global Production and Reserves Situation

<table>
<thead>
<tr>
<th>USGS 2017 Report</th>
<th>2017 Prod (Mt/yr)</th>
<th>Prod % of global</th>
<th>Reserves (Mt)</th>
<th>Reserves % of global</th>
<th>Life (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morocco_and_Western_Sahara</td>
<td>27</td>
<td>10%</td>
<td>50,000</td>
<td>71%</td>
<td>1,852</td>
</tr>
<tr>
<td>China</td>
<td>140</td>
<td>53%</td>
<td>3,300</td>
<td>5%</td>
<td>24</td>
</tr>
<tr>
<td>United_States</td>
<td>28</td>
<td>11%</td>
<td>1,000</td>
<td>1%</td>
<td>36</td>
</tr>
<tr>
<td>Rest of the World</td>
<td>68</td>
<td>26%</td>
<td>15,939</td>
<td>22%</td>
<td>234</td>
</tr>
<tr>
<td>World_total_(rounded)</td>
<td>263</td>
<td>100%</td>
<td>70,000</td>
<td>100%</td>
<td>266</td>
</tr>
</tbody>
</table>
A Substance Flow Model for Global Phosphorus

**Goal:** How effective are different approaches for conserving phosphorus resources?

**Objective:** Determine sensitivity and interactions of global phosphate rock demand with various efficiency parameters, including:

- AFD – Animal Fraction in the diet (meat and dairy)
- PUE – Agricultural Phosphorus Use Efficiency
- MUE – Manure Use Efficiency
- FWF – Food Waste Fraction
- FRE – Food Waste Recycling Efficiency
- WRE – Human Waste Recycling Efficiency
Modified Figure 2, data from Table 1.

Food ingested = 13.4% of
Mining + Imported PR
- All exports
- Non-food uses
### Model Inputs – Demand-driven Model

<table>
<thead>
<tr>
<th>Intervention efficiency parameters</th>
<th>Definition</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRE</td>
<td>Human Waste Recycling Efficiency</td>
<td>RW/HC</td>
</tr>
<tr>
<td>FWF</td>
<td>Food Waste Fraction</td>
<td>FW/FS</td>
</tr>
<tr>
<td>FRE</td>
<td>Food Waste Recycling Efficiency</td>
<td>RF/FW</td>
</tr>
<tr>
<td>AFD</td>
<td>Animal Fraction in the diet (as P)</td>
<td>AF/FS</td>
</tr>
<tr>
<td>MUE</td>
<td>Animal Manure Use Efficiency</td>
<td>RM/AM</td>
</tr>
<tr>
<td>PUE</td>
<td>Ag Phosphorus Use Efficiency</td>
<td>CH/(FA+RI+NS)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gmax</td>
</tr>
<tr>
<td>IU</td>
</tr>
<tr>
<td>NS</td>
</tr>
<tr>
<td>NP</td>
</tr>
<tr>
<td>PPC</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed model parameters</th>
<th>Definition</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>b_LD</td>
<td>Landfill disposal ratio</td>
<td>LD/(HC+RW)</td>
</tr>
<tr>
<td>b_WD</td>
<td>Waste discharge ratio</td>
<td>WD/(HC-RW)</td>
</tr>
<tr>
<td>Y_A</td>
<td>Yield of animal products</td>
<td>AF/(AC+LF+G +CA)</td>
</tr>
<tr>
<td>b_CA</td>
<td>Fertilizer grazing ratio</td>
<td>CA/AC</td>
</tr>
<tr>
<td>b_LF</td>
<td>Feed additive ratio</td>
<td>LF/AC</td>
</tr>
<tr>
<td>b_HL</td>
<td>Harvest loss ratio</td>
<td>HL/(VF+AC)</td>
</tr>
<tr>
<td>b_CL</td>
<td>Crop loss ratio</td>
<td>CL/CU</td>
</tr>
<tr>
<td>b_CR</td>
<td>Crop residue ratio</td>
<td>CR/CU</td>
</tr>
<tr>
<td>b_EL</td>
<td>Erosion loss ratio</td>
<td>EL/CU</td>
</tr>
<tr>
<td>b_HR</td>
<td>Harvest index</td>
<td>CH/CU</td>
</tr>
<tr>
<td>b_FF</td>
<td>Fuel and fiber ratio (Mt/yr/Gp)</td>
<td>FF/NP</td>
</tr>
<tr>
<td>b_FPE</td>
<td>Fertilizer production efficiency</td>
<td>FA/PA</td>
</tr>
<tr>
<td>b_PG</td>
<td>Fraction of PR to phosphogypsum</td>
<td>PG/PR</td>
</tr>
</tbody>
</table>

| Conv | Conversion factor (Mt/yr) / (g/cap/d): | NP*365.25/1000 | 2.45 |
## Spreadsheet Implementation

<table>
<thead>
<tr>
<th>Label</th>
<th>Flow Variable</th>
<th>Calculation</th>
<th>(Mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC</td>
<td>P in diet</td>
<td>PPC*Conv</td>
<td>3.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUMANS AND WASTE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HW</td>
<td>Excreta</td>
<td>HC</td>
<td>3.06</td>
</tr>
<tr>
<td>RW</td>
<td>Wastewater or excreta reuse (to ag soils)</td>
<td>WRE*HW</td>
<td>0.31</td>
</tr>
<tr>
<td>LD</td>
<td>Landfill</td>
<td>b_LD*(HW-RW)</td>
<td>1.24</td>
</tr>
<tr>
<td>WD</td>
<td>Surface water discharge to environment</td>
<td>b_WD*(HW-RW)</td>
<td>1.51</td>
</tr>
<tr>
<td>FOOD SUPPLY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>Total food supply (VF+AF)</td>
<td>HC/(1-FWF)</td>
<td>4.19</td>
</tr>
<tr>
<td>AF</td>
<td>Animal-based food supply (total)</td>
<td>FS*AFD</td>
<td>0.63</td>
</tr>
<tr>
<td>VF</td>
<td>Vegetal-based food supply</td>
<td>FS-AF</td>
<td>3.56</td>
</tr>
</tbody>
</table>

---

*HC*: P in diet

*PPC*: Conv

*HC*: Excreta

*WRE*: HW

*b_LD*: (HW-RW)

*b_WD*: (HW-RW)

*HC*: Total food supply (VF+AF)

*HC*: Animal-based food supply (total)

*HC*: Vegetal-based food supply

---

*Sustainable Phosphorus Alliance*
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</tr>
<tr>
<td>VF</td>
<td>Vegetal-based food supply</td>
<td>FS-AF</td>
<td>3.56</td>
</tr>
<tr>
<td><strong>FOOD OUTPUTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FW</td>
<td>Food waste</td>
<td>FWF*FS</td>
<td>1.13</td>
</tr>
<tr>
<td>RF</td>
<td>Organic solid waste input (from food)</td>
<td>FW*FRE</td>
<td>0.20</td>
</tr>
<tr>
<td>FL</td>
<td>Food chain losses (food waste, distr. Etc.)</td>
<td>FW-RF</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>DOMESTIC ANIMALS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AI</td>
<td>Total animal P inputs (AC+LF+CA+G)</td>
<td>AF/Y_A</td>
<td>16.34</td>
</tr>
<tr>
<td>G</td>
<td>Grazing input utilized</td>
<td>MIN(Gmax,Al)</td>
<td>12.10</td>
</tr>
<tr>
<td>FI</td>
<td>Fertilized input to animals (AC+CA+LF)</td>
<td>AI-G</td>
<td>4.24</td>
</tr>
<tr>
<td>AC</td>
<td>Animal feed</td>
<td>FI/(1+b_CA+b_LF)</td>
<td>2.66</td>
</tr>
<tr>
<td>LF</td>
<td>Livestock feed additives</td>
<td>b_LF*AC</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>ANIMAL MANURE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AM</td>
<td>ANIMAL MANURE</td>
<td>Al-AF</td>
<td>15.71</td>
</tr>
<tr>
<td>RM</td>
<td>Applied to soil</td>
<td>AM*MUE</td>
<td>7.86</td>
</tr>
<tr>
<td>ML</td>
<td>Lost to the environment</td>
<td>AM-RM</td>
<td>7.86</td>
</tr>
<tr>
<td><strong>HARVEST</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FF</td>
<td>Fuel and Fiber</td>
<td>b_FF*NP</td>
<td>1.04</td>
</tr>
<tr>
<td>HL</td>
<td>To post-harvest losses</td>
<td>b_HL*(VF+AC)</td>
<td>0.92</td>
</tr>
<tr>
<td>CH</td>
<td>Crop Harvest</td>
<td>VF+AC+HL+FF</td>
<td>8.18</td>
</tr>
<tr>
<td><strong>CROPS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CR</td>
<td>Crop residues (recycled to soil)</td>
<td>b_CR*CH</td>
<td>1.36</td>
</tr>
<tr>
<td>CA</td>
<td>Fertilizer to pasture</td>
<td>b_CA*AC</td>
<td>0.66</td>
</tr>
<tr>
<td>CU</td>
<td>Crop uptake</td>
<td>(CH+CR+CA)/(1-b_CL)</td>
<td>13.60</td>
</tr>
<tr>
<td>CL</td>
<td>Crop losses to the environment</td>
<td>b_CL*CU</td>
<td>3.40</td>
</tr>
<tr>
<td><strong>ARABLE SOIL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI</td>
<td>Recycle inputs (CR+RM+RF+RW)</td>
<td>CR+RM+RF+RW</td>
<td>9.73</td>
</tr>
<tr>
<td>EL</td>
<td>Soil erosion losses to the environment</td>
<td>b_EL*CU</td>
<td>6.80</td>
</tr>
<tr>
<td>SS</td>
<td>Soil storage</td>
<td>FA+NS+RI-EL-CU</td>
<td>6.85</td>
</tr>
<tr>
<td><strong>FERTILIZER</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA</td>
<td>Fertilizer Applied to Soil</td>
<td>MAX(0,(CH-PUE*(RI+NS))/PUE)</td>
<td>14.52</td>
</tr>
<tr>
<td>PA</td>
<td>Phosphoric Acid to Fertilizer</td>
<td>FA/b_FPE</td>
<td>15.46</td>
</tr>
<tr>
<td>DL</td>
<td>Distribution losses</td>
<td>PA-FA</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>PHOSPHORIC ACID manufacturing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IU</td>
<td>Industrial uses</td>
<td>IU</td>
<td>1.80</td>
</tr>
<tr>
<td>PR</td>
<td>BENEFICIATED PHOSPHATE ROCK</td>
<td>(LF+PA+IU)/(1-b_PG)</td>
<td>19.14</td>
</tr>
<tr>
<td>PG</td>
<td>Loss to phosphogypsum storage</td>
<td>b_PG*PR</td>
<td>0.96</td>
</tr>
</tbody>
</table>
Results – Sensitivity of PR Demand to Recycling of Food, Human Waste, Manure

![Graph showing the sensitivity of PR demand to recycling of food, human waste, and manure. The graph plots PR demand (Mt/y) against recycling percentages ranging from 0% to 100%. Lines represent different recycling scenarios: FRE, WRE, MUE.](image-url)
Interaction between Meat in the Diet and Manure Recycling

![Graph showing interaction between meat in the diet and manure recycling]

- PR (Mt/y)
- AFD
- MUE = 50%
- MUE = 75%
- MUE = 100%
- Nominal
Cost of Animal Food in Grain

<table>
<thead>
<tr>
<th></th>
<th>Milk</th>
<th>Carp</th>
<th>Eggs</th>
<th>Chicken</th>
<th>Pork</th>
<th>Beef</th>
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</thead>
<tbody>
<tr>
<td>Feed conversion (kg of feed/kg⁻¹ of live weight)</td>
<td>0.7</td>
<td>1.5</td>
<td>3.8</td>
<td>2.3</td>
<td>5.9</td>
<td>12.7</td>
</tr>
<tr>
<td>Feed conversion (kg of feed/kg⁻¹ of edible weight)</td>
<td>0.7</td>
<td>2.3</td>
<td>4.2</td>
<td>4.2</td>
<td>10.7</td>
<td>31.7</td>
</tr>
<tr>
<td>Protein content (% of edible weight)</td>
<td>3.5</td>
<td>18</td>
<td>13</td>
<td>20</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Protein conversion efficiency (%)</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>25</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 5. Protein contents of major animal foods and feed conversion efficiencies of their production. (Based on Figure 8.4 in ref. 2.) Calculations of feed conversion efficiencies based on the latest (1999) average US feed requirements from ref. (49); they include the feeding requirements of entire breeding and meat-producing populations.
PUE – Agricultural Phosphorus Use Efficiency, and FWF – Fraction of Food Wasted
Relative Sensitivity of Interventions (%Δ PR / %Δ Intervention)

<table>
<thead>
<tr>
<th>Intervention efficiency parameters</th>
<th>Rel. Sens.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRE  Food Waste Recycling Efficiency</td>
<td>0.012</td>
</tr>
<tr>
<td>WRE  Human Waste Recycling Efficiency</td>
<td>0.018</td>
</tr>
<tr>
<td>MUE  Animal Manure Use Efficiency</td>
<td>0.46</td>
</tr>
<tr>
<td>FWF  Food Waste Fraction</td>
<td>-0.98</td>
</tr>
<tr>
<td>AFD  Animal Fraction in the diet (as P)</td>
<td>-1.78</td>
</tr>
<tr>
<td>PUE  Ag Phosphorus Use Efficiency</td>
<td>1.58</td>
</tr>
<tr>
<td>NP  World Population</td>
<td>-2.83</td>
</tr>
</tbody>
</table>

Reducing Food Waste Fraction (FWF) is 82 times as effective as increasing Food Recycling Efficiency (FRE)
Effect of Population Interacting with % meat in diet

Global Phosphate Rock Demand (Mt/y) vs Population (billions)

- MFD = 15%
- MFD = 10%
The Challenge with Animal Food in Diet

GLOBAL MEAT DEMAND GROWTH ESTIMATES 2010 – 2030

Source: Rabobank (2011)

Sustainable Phosphorus Alliance
UNEP Population change projections (Millions per year)
Conclusions

- [Animal Food in Diet] interacts significantly with [Manure Use Efficiency] and [Ag Phosphorus Use Efficiency], but retains its high sensitivity.

- [Animal Food in Diet] has a non-zero optimum due to grazing input.

- [Ag Phosphorus Use Efficiency] and [Food Waste Fraction] exhibit diminishing returns.

- [Food waste fraction] is much more significant than [Food waste recycling].

- Effect of [Population] is significantly affected by [Animal Food in Diet].

- **Sensitivity** must be interpreted in terms of costs of implementation.

- **Substance Flow Modeling** is a viable planning tool for resource sustainability.
Recommendations

- De-aggregate by country or region
- De-aggregate food categories
- Develop dynamic models
- Develop cost factors for interventions and determine sensitivity to cost
Thank you and Save the P!
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• 8:45 Keynote: Dr Sally Rockey (FFAR)
• 9:30 Dr David Vaccari (Stevens Inst of Technology) “A Substance Flow Model for Global Phosphorus”
• 10:00 Coffee & networking
• 10:30 Dr. Luis Herrera (CINVESTAV), GMO technology for phosphite fertilizer use
• 11:00 Dr Kevin Dooley (ASU) & Allison Thomson (Field to Market): Market drivers of nutrient sustainability
• 12:00 – 1:30 Lunch & networking
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Crops only use 20-30% of the fertilizer applied in agriculture.

Over 35 million tons of Pi-fertilizer are applied annually to increase crop yield.
70% of the world’s arable land has low Pi availability (red and yellow areas) and require Pi fertilization.

Figure 1. Map of global soil phosphorus availability. The dominance of red and light-gray colors, indicating suboptimal phosphorus availability for the growth of many plant species, indicates the importance of phosphorus availability as a primary limitation to plant productivity in terrestrial environments (from Jaramillo-Velastegui, 2011).
Because of its low solubility and low mobility, Pi is the most limiting nutrient in the soil.
Phi was proposed after Second World War as a superior alternative source of P fertilizer over Pi because of its physicochemical properties:

- Phi solubility is less dependent on pH than Pi.
- Phi is less reactive than Pi with soil components.
- Phi is already widely used in agriculture as an effective treatment against Oomycetes (i.e. Phytophthora, etc.).
- No toxicity reported for humans and animals (FDA).
The problem: plants cannot use phosphite as a P source

Demonstrated in many species including monocots and dicots.
Given the advantages of Phi as a potential fertilizer, can we engineer plants to metabolize phosphite?
A few bacterial isolates are capable of using Phi as P source.

A phosphite assimilation operon was characterized in *Pseudomonas stutzeri WM88* by the Metcalf group. This operon includes *ptxD*, a gene encoding a highly specific oxidoreductase for Phi that allows this bacterium to use it as a sole P source.

Growth of transgenic tobacco plants in a sterile, inert substrate supplemented with Phi

<table>
<thead>
<tr>
<th></th>
<th>NO P</th>
<th>PHOSPHATE</th>
<th>PHOSPHITE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>20 40 80</td>
<td>20 40 80</td>
</tr>
<tr>
<td>mg.kg⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Transgenics are able to use Phi as sole P source with a phenotype and yield comparable to non transformed control plants grown in Pi.

In natural soils, PTXD plants fertilized with Phi require 50% lower P input to achieve maximum productivity.

Pi: orthophosphate
Phi: phosphite

Herbicide resistant weeds are making herbicides obsolete

The dramatic increase in herbicide-resistant weed biotypes; a major concern worldwide
Why is innovative weeding so important?

- Weeds are responsible for at least 10% of all yield losses.
- Weeds are strong competitors for crop and tree seedlings.
- Weeding people cannot work in more qualified jobs.
- Herbicides residues produce health risks.
- Herbicide resistant weeds are becoming an increasingly important problem for agriculture.
- Weedy algae and other biological contaminant prevent the cost effective use of microalgae for the production of biofuels and other high value products.
Phi is not a herbicide, however, it cannot be used as a source of P by conventional plants and inhibits their growth because it competes with Pi for the entry into the plant via a common set of transporters.

Can Phi be used to selectively fertilize crops and reduce weed growth?

Can we replace Pi fertilizer and herbicides with Phi?
Phosphite fertilization effectively suppresses weed growth under field conditions (soil with low Pi availability; 8ppm)
Effect of phosphite 4 weeks after treatment compared to glyphosate
Field trial with transgenic tobacco in Argentina

Pi: phosphate
Phi: phosphite
The Phi-technology is applicable to many crop species (maize and soybean)

In collaboration with Kan Wang, ISU. López-Arredondo et al., unpublished data.
The PTXD gene can be used as an effective selectable marker for many plant species.

In collaboration with the Pioneer/Dupont soybean transformation group and Kan Wang (Iowa State Transformation Center).
Competition experiment between *ptxD*-transgenic cotton and a broad leaf-type weed

In collaboration with Kertii Rathore Texas A&M. López-Arredondo et al., unpublished data.
Biomass accumulation of weed and \textit{ptxD}-transgenic cotton plants in phosphate and phosphite fertilized conditions

In collaboration with Kertii Rathore Texas A&M. López-Arredondo et al., unpublished data.
Competition of $ptxD$-transgenic cotton with natural weeds from an agricultural soil rich in weed seed

In collaboration with Kertii Rathore Texas A&M. López-Arredondo et al., unpublished data.
The phosphite system controls weed growth allowing weeds to decrease soil erosion and water evaporation.

Field tests in Argentina.
Potential benefits of the Phi-technology

**Advantages**

1. A single gene can be used as selectable marker trait.
2. Reduction in the application of P-fertilizer.
3. Reduction in the application of herbicides.
4. Potential protection against fungal infections.
5. Reduction in contamination of rivers, lakes and oceans.
6. Benefits to human animal health by reducing the application of agrochemicals.
7. Less harm to native biodiversity because Phi is not a herbicide.
8. No permanent accumulation of Phi in the soil because it is naturally oxidized by atmospheric $O_2$ into Pi. It last only a few months (2-3) in the soil.
9. Reduced carbon emissions by replacing the application of two compounds by a single one with dual effects.

**Disadvantages:**

1. It does not work in soils with high Pi availability.
2. It needs to be integrated carefully to properly manage fertilization and weed control, to optimize application for different soils.
Transgenic *C. reinhartii* expressing PTXD are able of using phosphite as a sole phosphorus source.
Engineered \textit{C. reinhartii} outcompetes the faster growing \textit{Scenedesmus obliquus} in media containing Phi as a sole P source.
Transgenic *C. reinhartii* grown in media containing phosphite can outcompete a natural mix of bacteria and microlagae.
The phosphite system is also applicable for the selective growth of cyanobacteria in open air systems (*Synechococcus elongatus*).
Metabolic engineering of microbial competitive advantage for industrial fermentation processes

A. Joe Shaw, Felix H. Lam, Maureen Hamilton, Andrew Consiglio, Kyle MacEwen, Elena E. Brevnova, Emily Greenhagen, W. Greg LaTou, Colin R. South, Hans van Dijken, Gregory Stephanopoulos
Funding

Kan Wang - Iowa State U
Kazimierz Wrobel - U Guanajuato
Keertii Rathore - Texas A&M
Eric Lyons - U. Arizona
Victor Albert - SUNY-Buffalo
Phosphorus Forum 2018
February 27, 2018 | Tempe, AZ

phosphorusalliance.org/events
#Phorum18

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Sustainable Supply Chains for Commodity Crop Sourcing

Allison Thomson, Science & Research Director
Phosphorus Forum, February 27, 2018
Producing enough food, fiber and fuel for more than 9 billion people by 2050, while conserving natural resources has become increasingly complex.

- 50-70% in middle class
- Purchasing more protein rich foods
- Doubling agricultural output
- Facing a changing climate
- Decreased rainfall
- Extreme weather patterns
- 70% fresh water used
- 37% of land use
- 1/3 edible food lost or wasted

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Changing Tastes

When shopping for food, consumers prize family satisfaction above all else, but increasingly, they consider sustainability as an important factor in their buying decisions.

More than 8 in 10 Americans consider sustainability when buying food and would like to see more options available that protect the environment.

Similarly, consumers are looking to companies to help them understand their impact on the environment – with nearly 3/4 of consumers stating they want companies to do a better job explaining how their purchases impact the planet.

Increasingly, we’re seeing Millennials voting with their wallets, with 6 out of 10 willing to pay more for environmentally friendly products.
• Reduce GHG emissions across value chain by 25% by 2020
• Sustainably source key agricultural ingredients by 2020
• Expand acreage in Field to Market to 1 Million acres by 2020

• Sustainably source 100 percent of 10 priority ingredients by 2020
• Expand acreage in Field to Market to 2.5 Million acres by 2015
• Reduce GHG emissions in fertilizer management

• Halve the GHG impact of our products across the lifecycle by 2020
• Source 100% of our agricultural raw materials sustainably by 2020
• Halve the environmental footprint of the making and use of our products as we grow our business by 2020

• Fertilizer optimization on 14 Million acres of U.S. farmland by 2020
• Reduce emissions in our supply chain by 1 gigaton (1 billion metric tons) by 2030
Field to Market: The Alliance for Sustainable Agriculture focuses on defining, measuring and advancing the sustainability of food, fiber and fuel production
Guiding Principles

- Engage the full supply chain
- Drive continuous improvement
- Focus on commodity crops
- Provide collaborative leadership

- Transparent
- Grounded in science
- Remain technology neutral
- Focused on outcomes
- Offer useful measurement tools & resources
- Coordinated and comprehensive approach
Delivering Sustainable Outcomes

Benchmarking Sustainability Performance

Catalyzing Continuous Improvement

Enabling Sustainability Claims

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Fieldprint® Platform

Provides corn, cotton, potato, rice, soybean and wheat growers with a free and confidential tool to explore relationships between management practices and sustainability outcomes.

- Helps growers evaluate their farming decisions in the areas of:
  - Biodiversity (Piloting)
  - Energy use
  - Greenhouse gas emissions
  - Irrigated water use
  - Land use
  - Soil carbon
  - Soil conservation
  - Water quality

- Farmers can save their information and compare the environmental impact of different management decisions on their operation.
Phosphorus and Environmental Outcomes

- The Fieldprint Platform asks growers for the amount and timing of applications for organic and inorganic fertilizers

- **Energy Use and Greenhouse Gas Emissions Metrics**
  - The energy and greenhouse gas emissions associated with manufacture of inorganic fertilizer are accounted for
  - The energy and greenhouse gas emissions associated with field application of all fertilizers is accounted for

- **Water Quality Metric**
  - The amount of fertilizer applied and conservation practices adopted determine the nutrient component of the water quality score.
Field to Market efforts on water quality

- One of the eight sustainability outcomes we calculate is Water Quality
  - Using the NRCS Water Quality Index as a qualitative indicator of the risk of loss of nutrients, sediment and pesticides
  - Also include a quantitative measure of soil erosion (RUSLE2 and WEPS)

- Membership interest in a more informative, robust metric for driving continuous improvement and enabling supply chain reporting
  - Can we provide farmers with individual field performance – specifically surface and sub-surface nutrient losses – that are quantitative, accurate and actionable?

- Embarked on efforts to develop and test ideas for quantitative metrics based on scientific models
  - Initial proof of concept (2016)
  - Review of available tools and data (2017)
  - Field level pilot project (2018)
Growers and members of the food, fiber and fuel value chain are partnering to demonstrate the value that outcomes-based sustainability metrics and the Fieldprint Platform bring to promoting continuous improvement in sustainability outcomes and helping advance more sustainable production.

45 Fieldprint® Project Collaborations

Barley
Corn
Cotton
Potatoes
Rice
Soybeans
Sugar Beets
Wheat
Field to Market 2017 Collaboration of the Year: Kellogg’s Origins Great Lakes Fieldprint Project

Kellogg’s partnering with Syngenta and The Nature Conservancy
• Using the Field to Market Metrics to help farmers understand their sustainability outcomes
• Training Certified Crop Advisors through sponsorship of an RCPP in the watershed, ensuring technical assistance and cost-share programs are available to farmers to improve on their sustainability scores
• Annual grower workshop hosted by project partner organizations to share sustainability results and connect growers to additional resources
• Focusing on soil health (cover crops and reduced tillage) and nutrient management practices to improve water quality
• 7000 acres of soft winter wheat have been enrolled in the program
• Kellogg’s can use the aggregate results in sustainability reporting and claims for their products

“To me, the real definition of ‘sustainability’ is ensuring that my kids are going to have somewhere to farm,” said Rita Herford, participating wheat farmer, Minden City, Michigan. “It's doing things right, it's doing things environmentally friendly, keeping the soil healthy, replenishing nutrients into the soil, because if we don't have land to farm on, if we don't keep that quality up, we don't have a farm.”
How it Works: Improving water quality in Indiana

Conservation Technology Information Center leads project in Big Pine Creek Watershed

• Project partners include all elements of the supply chain:
  • Corn and soybean farmers, Indiana Soybean Alliance, National Soybean Board
  • Corporate members Tate & Lyle, Coca-Cola and Land O’ Lakes
  • Conservation and technical assistance from The Nature Conservancy, local Soil & Water Conservation Districts, and NRCS
• Participating farmers required to enter data and meet with a Certified Crop Advisor to evaluate results and opportunities.
• Eligible and interested growers connected with cost share opportunities for conservation practice adoption and other NRCS programs.
• > 2000 acres enrolled in 2017
Collaboration and transparency within the supply chain is key to answering consumer questions on where and how their food, fiber and fuel are produced.

Field to Market supports the food and agriculture in answering these questions by aggregating field-level data in a standardized and anonymized fashion to make three types of sustainability claims:

- Participation Claims
- Measurement Claims
- Impact Claims
**Field to Market and Phosphorus**

- **Water quality**: Moving towards adoption of improved NRCS tools and an eventual quantitative metric
  - Better characterization of the specific water quality risk
- **4R Collaboration**: Working with IPNI, TFI and others to advance the science and adoption of 4R management practices
  - Better guidance on what practices lead to improvements
  - Better measurements to give credit for improvements
- **Expanding the program**: Additional crops and cropping systems; account for other crop amendments and any difference in the energy/resource cost of production
- **Science Engagement**: Continue to collaborate with the scientific community on best representation of the environmental impacts resulting from crop management.
Sustainability Data in Agricultural Supply Chains
Dr. Kevin Dooley, Chief Scientist, TSC

February 2018
The “I don’t know” barrier in Walmart Sustainability Index

Food, Beverage, and Ag Products: 2015-16 Data

89% of 13,475 scores of 0 result from “We are unable to determine at this time”

<table>
<thead>
<tr>
<th>Score range</th>
<th>2015</th>
<th>2016</th>
</tr>
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<tbody>
<tr>
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<tr>
<td>(90 - 100)</td>
<td>(90 - 100)</td>
<td>(90 - 100)</td>
</tr>
</tbody>
</table>

Total Respondents: 1,137 (2015) vs. 1,847 (+62%) (2016)
Average Score: 30.5 (2015) vs. 34.1 (+12%) (2016)
Challenge: As commodities move downstream, sustainability data is left behind

Current TSC’s KPI survey efforts highlight a breakdown in the ability for supply chains to address on-farm characterization stemming from a number of sources.
Data landscape mapping in Ag supply chains
Enhancing Data Flows through Interoperability of Systems

- Traceability and data interoperability only first step

- Need to create incentives to engage in information request

- Need to create incentives, address barriers to adoption of sustainable ag practices

Data Entry Challenge:
Need for alignment and interoperability of grower input data for plug and play with various standards

Workstream #1: Assess data input requirements across tools within areas of overlap

Data Conversion:
Need for Rosetta Stone to leverage data from various standards

A critical challenge for the ag supply chain is streamlining data entry for growers and converting this information into a useable format for retailers.
Supply network mapping exercise

What are the market incentives, barriers, and solutions to adoption of more sustainable phosphorus practices?

1. Form into small teams
2. Draw a supply network for a particular commodity, from farm to retail to final disposition
   - Nodes are organization types (e.g. grower)
   - Arrows represent flow of material, information
3. Use network as basis to answer discussion question
4. Report out
Why Brands and Retailers Need Farm-Level Sustainability Data: Use cases for IT solutions

- This session will highlight the need for IT solutions to mobilize data across farm, brands, and retailers and will also provide the business case for you to communicate the opportunities for software and system solutions in the agricultural data space to your company’s sustainability and procurement teams.

- Hear from brands and retailers about their needs for farm data – why they want it, how they use it, and how it can help them achieve their sustainability goals and commitments.

- Learn from growers who view sustainability as a business opportunity and how the data help with farm management decision making.

Wednesday & Thursday, May 2-3:
One hour sessions related to agriculture

- How Can TSC’s New Deforestation Model Help You Meet 2020 Zero Deforestation Commitments?
- Sustainable Commodities Supply Chain Report and Framework in Action Workshop
- From the Ground Up: Soil to Denim
- Corporate Investment in Smallholder Agriculture: A Business Case for Reducing Supply Risk and Improving Livelihoods
- Cases & Conversations: Examining Water Solutions Across Sectors