Agriculture

Accomplishments and opportunities

Dr. Martha Schlicher
Monsanto Company
Discussion topics

• The impact of technology on production today

• Illustrative public-private collaborative technology advancement efforts
  • Enabling the commercial viability of corn stover
  • Barriers to commercial viability of algal biofuels
  • Enabling technologies for parasite solutions
  • Informing models for better crop yield predictions

• How best to utilize future resources
The US has been prolific in delivering agricultural productivity; other countries are repeating the trend.

Source: Crop Science. Vol 46:528-543, USDA FAS and SAGARPA
The technical strides that have made this all possible are little known

- Global research investment in the genetic improvement of corn for yield
- Green Revolution – improved agronomics and conservation practices
- Development of equipment for planting, cultivating, harvesting, and storing corn
- The introduction of biotechnology and genomics
- Market and supply chain and channel development
Yield improvements to-date have resulted from technical advancements in three major areas:
Plant breeding is a system of evolving technologies that continue to increase genetic gain.

CORN BREEDERS MEASURED 3-5 TRAITS TO MAKE SELECTION DECISIONS

- **High Input/Complexity**
  - 1970
  - Low
  - 2000
  - Low
  - 2030

**Low-throughput Phenotype Selection**
Plant breeding is a system of evolving technologies that continue to increase genetic gain.
Stacking selection in the lab with selection in the field - rapidly mining our genetic library.

- Superior Genetics Advanced
- Automated Seed Chipping
- DNA Analysis and Selection of Superior Seeds
- Crop Yield and Agronomic Performance
- Phenotypic and Disease Evaluations

FIELD

LAB
The chipping revolution removes the bottleneck of hand sampling plant tissue

VS.

- **Labor intensive**
- **Time-consuming**
- **Low-throughput**

Capable of analyzing millions of samples per year!

Soy  Corn  Cotton  Melon  Wheat
Genomics allows testing of thousands of candidate genes for new biotech traits

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Billions of Bases</td>
<td>100,000’s of Genes</td>
<td>10,000’s of Genes</td>
<td>1,000’s of Genes</td>
</tr>
</tbody>
</table>

**Sequencing**
*Crops*: Corn, Soy, Cotton, Rice, Wheat, Sorghum, Tomato, Bean, etc.
*Models*: Arabidopsis, Medicago truncatula
*Microbes*: Aspergillus, Agrobacterium, Bt, etc.
*Pests*: CRW, SCN

Public data from hundreds of plant and microbial genomes

Gene Relationships

Transcript Profiling:
*Corn, Soy, Rice, Arabidopsis, etc.*
Thousands of candidate genes become tens of thousands of transformation events

**Gene Transfer to Agrobacterium**

*Agrobacterium* transfers the gene/trait into the chromosome of individual corn cells

**Gene Transfer to Corn Cell**

**Selection**

**Regeneration**

**Multiple Events per Trait**

**Seed with Trait**
**Automated phenotyping is a key enabler of massively-parallel gene screening**

### Assembly–Line Automation
- Automated Plant Handling
- Anticipatory Environmental Controls

### Plant Growth and Physiology
- Corn
- Soy
- Cotton
- Drought and Reduced Nitrogen Conditions
- Same Seed is Tested in Field

### Image Analysis
- Daily Imaging and Growth Rate
- 1000s of Measurements per Gene
- Visible and Hyperspectral Imaging

### Robust Data Systems
Integrated Farming Systems\textsuperscript{SM} would combine advanced seed genetics, on-farm agronomic practices, software and hardware innovations to drive yield.

**DATABASE BACKBONE**
Expansive product by environment testing makes on-farm prescriptions possible.

**Breeding**
Significant increases in data points collected per year to increase annual rate genetic gain.

**Yield Monitor**
Advances in Yield Monitoring to deliver higher resolution data.

**Variable-Rate Fertility**
Variable rate N, P & K “Apps” aligned with yield management zones.

**Precision Seeding**
Planter hardware systems enabling variable rate seeding & row spacing of multiple hybrids in a field by yield management zone.

**Fertility & Disease Management**
“Apps” for in-season custom application of supplemental late nitrogen and fungicides.
Opportunities for even further yield improvement are evident today

Corn yield differences – Monsanto trials versus “county “averages

<table>
<thead>
<tr>
<th>Country</th>
<th>Open Pollinated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>0%</td>
</tr>
<tr>
<td>France</td>
<td>0%</td>
</tr>
<tr>
<td>United States</td>
<td>0%</td>
</tr>
<tr>
<td>Mexico</td>
<td>71%</td>
</tr>
<tr>
<td>Brazil</td>
<td>27%</td>
</tr>
<tr>
<td>India</td>
<td>54%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>20%</td>
</tr>
<tr>
<td>Philippines</td>
<td>41%</td>
</tr>
</tbody>
</table>
Enabling the commercial viability of corn stover harvest
A focus on increasing corn grain yield increased corn stover yield and resiliency

Harvest index vs. grain yield

Planting 2\textsuperscript{nd} yr corn in Nebraska

\textbf{2008 trials} - 13 locations, 14 unique hybrids (101 to 111RM)

Grain makes up about 58\% of the biomass in a field at harvest

Stover (stalks, cobs, leaves) makes up about 42\% of the biomass

\begin{itemize}
  \item \textbf{200 bu/ac field} 
  \begin{itemize}
    \item 4.8 dry tons/ac
    \item 3.4 dry tons/ac
  \end{itemize}
\end{itemize}
Growers needed demonstrated and sustainable economic removal solutions

- Properly done, corn stover harvests will increase the value of an acre of corn
- Improperly done, corn stover harvests will damage fields
Policy has created a lot of interest in stover removal. The RFS mandates 36 billion gallons per year (BGY) of renewable fuels by 2022 with 16 BG to come from cellulosic feedstocks like stover.

Advanced can be anything except corn starch ethanol – is assumed to be mainly sugarcane.

GHG = greenhouse gas (carbon dioxide, methane, nitrous oxide all as CO$_2$ equivalents)
But there were many opinions on what is actually available to sustainably remove:

<table>
<thead>
<tr>
<th>Study</th>
<th>Spatial Extent</th>
<th>Annual Total Residue Sustainably Available (million metric tons)</th>
<th>Timeframe</th>
<th>Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>US</td>
<td>Iowa</td>
<td>Regional</td>
</tr>
<tr>
<td>Larson, 1979</td>
<td>Corn Belt, Great Plains, and Southeast</td>
<td>N/A</td>
<td>N/A</td>
<td>49.0</td>
</tr>
<tr>
<td>Nelson, 2002</td>
<td>37 states from the Great Plains to the East Coast</td>
<td>N/A</td>
<td>10.1</td>
<td>47.6</td>
</tr>
<tr>
<td>Sheehan et al., 2003</td>
<td>Iowa</td>
<td>N/A</td>
<td>40</td>
<td>N/A</td>
</tr>
<tr>
<td>Nelson et al., 2004</td>
<td>10 Corn Belt and Great Plains States</td>
<td>N/A</td>
<td>59.5</td>
<td>430.3</td>
</tr>
<tr>
<td>Perlack et al., 2005;</td>
<td>Whole US</td>
<td>176</td>
<td>14.5</td>
<td>176</td>
</tr>
<tr>
<td>Graham et al., 2007;</td>
<td>Whole US</td>
<td>58.3</td>
<td>13.7</td>
<td>58.3</td>
</tr>
<tr>
<td>Muth and Bryden, 2012</td>
<td>Iowa</td>
<td>N/A</td>
<td>26.5</td>
<td>N/A</td>
</tr>
<tr>
<td>Muth et al., 2012</td>
<td>Whole US</td>
<td>150.9</td>
<td>25.9</td>
<td>150.9</td>
</tr>
<tr>
<td>Muth et al., 2012</td>
<td>Whole US</td>
<td>207.9</td>
<td>37.3</td>
<td>207.9</td>
</tr>
</tbody>
</table>
A “Sustainable” harvest must meet both environment and economic requirements

Production and removal must provide value to all participants

- Every field is unique: averages are dangerous
- Sustainable removal levels will vary with yield
- Nutrient replacement costs will vary by field, year and markets
- Weather challenges will occur

Feedstock improvement

Improved tillage, planting and harvest

Biofuel/feed production Improvement
Information and data are being broadly shared and developed

- Coordinated Field Trials
  - Sustainability Metrics
  - Agronomic Practices
- Commercial Scale Trials
  - Learning Curves
  - Testing the Viability of Agronomic Strategies
- Decision Support
  - Advanced Computational Methods
  - Data Management
  - Tool Deployment
With a focus on sustainable residue removal

Focused on quantifying the limiting factors, so we can effectively develop the agronomic strategies.
A modeling framework was developed for planning

- Quantitative Soil C Analysis
- Green House Gas Fluxes
- Water Quality Impacts
- Crop Practice Strategies
Direction on best residue management is critical

**Approach**

Simulation Models

Field Management Decisions

Databases - e.g. SURGO

The models and databases exist,

The Residue Management Tool provides a framework where models can plug together to answer questions using available data.
Understanding sustainable harvest: Sub-field scale variability

(a) Organic Matter in the top horizon (%)
(b) Sand Fraction in the top horizon (%)
(c) Surface Slope (%)
(d) Grain Yield (Mg ha⁻¹)
(e) Residue Removal Rate (Mg ha⁻¹)
(f) Sustainable

SCI < 0
Erosion > T
SCI < 0
Erosion > T
Ultimately slope, rotation, yield and climate dictate sustainable stover removal rates

Corn yield required to sustainably remove 1 dry ton/ac corn stover

Average 2009 corn yield: 191 bu/ac

- Corn after corn
- Corn/corn/soy
- Soy/corn

Benton County, Iowa harvest rate estimates
The economics of stover harvest determine use

Economic modeling study from Purdue use costs from stover project

Stover supply vs. price

Farmer planting decisions vs. price

Corn Stover for Bioenergy Production: Cost Estimates and Farmer Supply Purdue Ag Extension Bulletin RE-3-W
http://www.extension.purdue.edu/extmedia/EC/RE-3-W.pdf
3 unusual years = “average” weather

2008 – Delayed crop, frequent light rains, stover harvest during two breaks in rainfall, 17 harvest days

2009 – Very delayed crop, frequent heavy rains, stover harvest during longer break in rainfall, 18 harvest days

2010 – Early crop, excellent weather, 22 harvest days

This is “average” weather

- Harvest day defined as 3rd dry day
- 3.2 ± 0.5 harvest days/wk (1988-2009)
- Assume 6 week harvest window
- “average” is 19.2 harvest days
- 2008 - 2010 average - 19 harvest days/yr
Stover biomass has alternative uses with alternative values

- Displace coal with 90% GHG reduction per BTU
- Produce cellulosic ethanol
- Produce animal feed

- Offsets additional corn or energy crop production
- Offsets additional corn production

Corn grain production
Stover
Lime treatment can improve feed value of corn stover

Ground stover Add calcium hydroxide and water Treated stover

Lime treatment reduces cell wall components that hinder digestibility

<table>
<thead>
<tr>
<th>Component</th>
<th>Percent reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetyl sugars</td>
<td>92%</td>
</tr>
<tr>
<td>Lignin</td>
<td>70%</td>
</tr>
<tr>
<td>Cellulose polymerization</td>
<td>56%</td>
</tr>
</tbody>
</table>


Improves *in vitro* digestibility by 30-50%
Economics are driving commercialization

- Lime treatment increases corn stalk nutritional value
- Treated stalks displace portion of corn in diet
- Grower makes incremental $30-$60/A
- Cattleman makes incremental $10-$20/head
- Stalks as feed effectively increases the productivity of the corn by 50 bu/acre
- Commercial operations developing

Corn stalks chopped

Treated with lime and transported

Bunkered for feeding

Heifers enjoying treated stalks
Recipe combines attachment, lime for new corn stover harvest method

Innovation creates cattle feed option, added crop value for farmers

“From a farmer-feeder standpoint, this is just an amazing opportunity, and you still have the corn as a revenue source,” Duane Kristensen said Thursday at a stover harvesting demonstration in his cornfield north of Minden.

“It’s almost like a double-crop situation …,” said farmer and KAAPA President Paul Kenney. “Stover is a crop. As long as we can keep up productivity and take the stover off, it’s a great benefit to us.”
Soil health: Manage to erosion and organic matter targets

Stover is required to maintain soil quality
- Reduces wind erosion
- Reduces water erosion
- Provides organic matter to soil

Soil organic matter
- Enhances soil water and nutrient holding capacity
- Improves soil structure (less crusting, compaction and erosion)
- Promotes higher crop yields

Conservation planning tools (RUSLE2, WEPS, and SCI) have been used to estimate field-specific stover retention targets

- University of Nebraska Extension: Harvesting Crop Residues http://www.ianpubs.unl.edu/epublic/pages/index.jsp?what=publicationD&publicationId=1026
Sustainable residue removal mobile application

Why a Mobile Application?
- Data acquisition and removal decisions are essentially simultaneous
- Need an informed answer that fits with existing workflows
- Engage regulators and conservation planners
- The foundations for mobile app deployment provide a strong platform for the next set of research questions
Mobile App Status

Availability
- URL: http://bioenergyldt.inl.gov/mobile
- Desktop URL: http://bioenergyldt.inl.gov
- Mobile App:
  - Available in the App Store in about 3-4 weeks
  - Currently distributed on a user-by-user basis from INL

Path Forward
- Current support 4 simultaneous users, will increase as necessary
- NRCS test plan
- Map selection interface
- Advanced agronomic strategies
- Advanced equipment designs
Strategies for increasing residue removal

Sustainable management options

- Lower removal rates via equipment choice or interval removal schemes
- Advanced equipment development, i.e. variable rate
- Agronomic strategies
  - Tillage
  - Cover crops
  - Landscape management concepts
Implementing sustainable harvest: Variable removal rates

- 200+ bu/acre corn

10 miles difference

- Less than 65 bu/acre
### Whole-Field Cover Crop Effects

<table>
<thead>
<tr>
<th>Rake and Bale Removal</th>
<th>Reduced Tillage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual Sustainable Residue (metric tons)</td>
<td>Percentage of Field Managed Sustainably</td>
</tr>
<tr>
<td>Modeling Scenario† 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Corn/Soy)</td>
<td>36</td>
<td>21%</td>
</tr>
<tr>
<td>Modeling Scenario 2</td>
<td>140</td>
<td>83%</td>
</tr>
<tr>
<td>(Corn/Rye/Soy)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Modeling designations from Table 4 in Karlen and Muth, 2012. Agrociencia Uruguay, Special Issue:98-106.

Impact of row crop production management decisions implemented within the whole field.
Barriers to commercial viability of algal biofuels
Algae for biofuels garnered enormous interest; feasibility was unclear

| Ethanol in enclosed photobioreactors, Florida, Mexico, collaboration with Dow Chemical |
| In 2009 DOE Announces $85 Million for Algal and Advanced Biofuels |
| Dick Sayre, Danforth center, “milking” & “heteroboost”, Hawaii then Southeastern US |
| Pilot-scale production in New Mexico planned for 2010 |
| Fermenters, starting with higher-value non-fuel products, collaboration with Chevron |
| Craig Venter, 2009 $600M collaboration with Exxon/Mobil |

**Algal Claims**
- Demonstrated >10x per acre yield than terrestrial crops
- Can utilize marginal land – no competition with food
- Can use CO₂ from smoke stacks (makes coal “green”)

**Algal Challenges**
- Energy drain: centrifugation and drying may consume more energy than is in the biofuel
- Needs added CO₂ to grow, so may be dependent on fossil fuels/locations
- Unsolved problems of scale & contamination
- Weekly harvesting
- Huge capital investment
Telcim: Modeling the production of microalgal biodiesel

If we assume that commercial-scale microalgal biodiesel production is technically feasible…

- **What is its Net Energy Return?**
- **How much will it cost?**
- **What is its carbon intensity?**

Mark Henson  
Department of Energy, Environmental and Chemical Engineering  
Washington University in St. Louis
TELCIM outputs: Cost, energy return, and carbon footprint

TOTAL CAPITAL COST = $4200 MM

BIODIESEL PRODUCTION COST = $9.71/gal

NER = 0.43 (JOULES OUT PER JOULE IN)
Single parameter sensitivity

- Oil Content (25%)
- Dewatered Algae Conc. (26.5%)
- Algae Productivity (24.75 g/m²/day)
- COD Removal Eff. (65%)
- CO₂ Conc. (15.5%)
- Power Plant Size (1000 MW)

Base Cost = $9.71/gal

-20% (rel.)
+20% (rel.)
Enabling technologies for parasite control
Public funding enables a network of ~50 collaborators to explore parasite structural and functional genomics of roundworms

400,000 nematode ESTs on the Net
John Parkinson¹, Makedonka Mitreva², Neil Hall³, Mark Blaxter¹ and James P. McCarter²

Genome Biology 2003. 4:R26

Analysis and functional classification of transcripts from the nematode Meloidogyne incognita
James P McCarter¹,², Makedonka Dautova Mitreva², John Martin², Mike Dante¹, Todd Wylie², Uma Rao³, Deana Pape¹, Yvette Bowers¹, Brenda Theising¹, Claire V Murphy², Andrew P Kloeck³, Brandi J Chiapelli², Sandra W Clifton³, David McK Bird³ and Robert H Waterston⁴

Genomic filtering: an approach to discovering novel antiparasitics
James P. McCarter

Genome Research

Comparative Genomics of Gene Expression in the Parasitic and Free-Living Nematodes Strongyloides stercoralis and Caenorhabditis elegans
Makedonka Mitreva,¹,³,⁶ James P. McCarter,¹,²,³ John Martin,¹ Mike Dante,¹ Todd Wylie,¹ Brandi Chiapelli,¹,² Deana Pape,¹ Sandra W. Clifton,³ Thomas B. Nutman,³ and Robert H. Waterston¹,⁴

mRNA sequences for Haemonchus contortus intestinal cathepsin B-like cysteine proteases display an extreme in abundance and diversity compared with other adult mammalian parasitic nematodes
Douglas P. Jasmer³,⁴, Makedonka Dautova, Mitreva², James P. McCarter³,⁵

Nematode.net: a tool for navigating sequences from parasitic and free-living nematodes
Todd Wylie¹,², John C. Martin¹, Michael Dante¹, Makedonka Dautova Mitreva¹, Sandra W. Clifton¹, Asif Chinwalla¹, Robert H. Waterston¹,³, Richard K. Wilson¹ and James P. McCarter¹,³


A transcriptomic analysis of the phylum Nematoda
John Parkinson¹,², Makedonka Mitreva¹, Claire Whitton², Marian Thomson², Jennifer Daub², John Martin¹, Ralf Schmid³, Neil Hall⁴, Bart Barrell¹, Robert H Waterston³,⁴, James P McCarter¹,² and Mark L Blaxter²
These data inform a pipeline to develop novel products to control plant & animal parasites

**DIVERGENCE – A Proven Discovery Pipeline**

*Targeting Genes…*

- Genome Data
- Informatics Selection
- RNAi Target Validation
- Target Gene Collection

*… Then Products*

- Nematicides
- Anti-parasitic Drugs
- Resistance Genes
- Vaccines
Informing models for predicting crop yields

Factors affecting maize production efficiency

Neumann et al., 2011
Dated economic and crop models are inadequate for current needs

• Current efforts to project the impact of climate change on current and future crop productivity are severely hampered by the weakness of the mechanistic crop simulation models

• Policy decisions for agriculture are using black box economic models instead of crop models

• Many of these models were developed using hybrids developed 20-30 years ago, and have not been significantly modified to incorporate results of recent physiology and agronomic research.

• The Agricultural Intercomparison & Improvement Project (AgMIP) was initiated to address these shortfalls

• Monsanto has donated the resources (data and personnel) to improve the DSSAT Ceres Maize corn simulation model: Posting/donating selected test-mean yields from MON global breeding trial database for use in model-validation

• Additional field phenology data (multi-site, multi-year) are needed to calibrate/validate the new model
AgMIP interlinks climate, crop, and economic models
Future challenges
A simple equation with complex solutions

BY 2030...

TODAY + 1.4 B PEOPLE + 100% INCREASE + 30% INCREASE

GLOBAL GRAIN DEMAND (M MT)

Source: IHS Global Insights, Agriculture Division
Grain ethanol use represents only a small portion of overall agricultural food and feed commodity use.

Even with projected 8x growth in China corn demand, surplus corn is available for renewables.

Grain ethanol remains <5% of global feed/food use.
U.S. agriculture supports food security globally, but R&D funding has been significantly outpaced by other industries.

<table>
<thead>
<tr>
<th>U.S. Agricultural Exports</th>
<th>1970 FY</th>
<th>2007 FY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Value*</td>
<td>$6.96 B</td>
<td>$82.2 B</td>
</tr>
<tr>
<td>Corn</td>
<td>12.9 MMT</td>
<td>61.9 MMT</td>
</tr>
<tr>
<td>Soybean</td>
<td>11.8 MMT</td>
<td>31.5 MMT</td>
</tr>
<tr>
<td>Wheat</td>
<td>20.2 MMT</td>
<td>34.4 MMT</td>
</tr>
<tr>
<td>Cotton</td>
<td>3.9 MMT</td>
<td>13.6 MMT</td>
</tr>
</tbody>
</table>

Sources: USDA ERS and USDA FAS PSD Database

*nominal dollars

**adjusted to 2001 dollars

**Monsanto estimate based on 2007 R&D spend reported by Phillips McDougall (agrochemical and seed industry) and NSF Industrial Research and Development Information System (food and ag-derived products manufacturing)
Development of the scientific workforce is critical.

### Ag and Food Industry Scientific & Technical Jobs

- **Only half as many qualified graduates to fill these jobs**

### Ag-Related Growth Occupations

<table>
<thead>
<tr>
<th>Occupation</th>
<th>% increase 2010-2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochemists/Biophysicists</td>
<td>37.4</td>
</tr>
<tr>
<td>Environmental Scientists</td>
<td>27.9</td>
</tr>
<tr>
<td>Hydrologists</td>
<td>18.3</td>
</tr>
<tr>
<td>Computer and Information Systems</td>
<td>16.9</td>
</tr>
<tr>
<td>Food Scientists</td>
<td>16.3</td>
</tr>
<tr>
<td>Soil and Plant Scientists</td>
<td>15.5</td>
</tr>
</tbody>
</table>

*Shortfall of plant geneticists/plant breeders*

---