Evaluating innovative conservation cropping systems at field scale:
- to produce all forage & feed, some fuel for average PA dairy farm
- minimize off-farm inputs & environmental impacts
- adapt to & mitigate climate change
Penn State NESARE Dairy Cropping Systems Team

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Typical Northeast Dairy Farm

Import Feed and Fertilizers

Grow forages on-farm: corn silage and alfalfa


Alf.+grass Corn Sil. Corn silage/ Rye cover crop Corn Sil. Alfalfa + Orchardgrass
Dairy Farm Nutrient Flow

Manure
75% nutrients

Manure
N P K

Milk
25% nutrients

Alfalfa drawing: Kristen Haider
Typical Pennsylvania Dairy Farm

65 milk cows + young stock
Forages only: 49 hectares

Manure 2087 MT/yr

Purchase Feed & Fertilizer: Nutrients accumulate & prone to loss

Manure N P K

H₂O

N P Sediment
Dairy Farm

Manure 2300 T

Plant no-till, inject manure, reduce N, P losses

Purchase $:
- Herbicide

Purchase LESS:
- Less Fertilizer
- Less fuel

Photos: Margaret Douglas, Robert Meinen
Compared surface broadcast to injected manure across 6 yr rotation:
- same rate of manure applied, PSNT to determine side-dress N

With injected manure used 33% less inorganic fertilizer N (100 kg/ha), maintained similar yields
Potential Climate Change Risks for Northeast Dairy Farms

- more soil erosion & nutrient loss in fall, winter, & spring due to rain & warmer temperatures promoting nutrient mineralization
Climate Change Potential Risks for Northeast Dairy Farms

- more soil erosion & nutrient loss in fall, winter, spring due to rain, warmer temperatures promoting nutrient mineralization

- difficulty timely planting of crops in wet soil, particularly in spring
Climate Change Potential Risks for Northeast Dairy Farms

- more soil erosion & nutrient loss in fall, winter, spring due to rain, warmer temperatures
- difficulty timely planting of crops in wet soil, particularly in spring
- summer yield declines with increased temperature, risk of drought
Climate Change Potential Risks for Northeast Dairy Farms

Higher Temp

rain

rain

rain

rain

Higher Temp

J F M A M J J A S O N D

F M A M J J A S O N D

F M A M J J A S O N D

F M A M J J A S O N D

- more pests, particularly diseases with moist and warm conditions, more insects, slugs, weeds
Climate Change Potential Gains for Northeast Dairy Farms

- Longer growing season, esp. in fall and spring
- Warmer temps all season may benefit northern regions
- Possible increased demand ($) for NE milk due to lower production in drier and warmer western climate
Enhance the Resiliency of Northeast Dairy Farms

More year-round crop production, utilize fall and early spring growing seasons

Keep soil covered more continuously, to prevent erosion, improve soil health and Utilize manure applications (not just cover crops)

Conservation Agriculture:
Reduce tillage, Produce and retain Crop Residue on Soil, Rotate Crops

Improve soil structure, prevent compaction and enhance water infiltration

Distribute planting, growth and harvesting operations over more seasons
Two Diverse 6 yr No-till Crop Rotations

Manure Rotation
- IPM for insect pests
- No Bt traits
- No seed insecticides
- Double & cover crops, perennials

Pest Rotation

Corn-soybean No-till rotation
- Triple-stacked Bt
- Seed insecticide
- Insecticide at planting (Warrior)
- No cover crop
Continuous cover

Crops that utilize manure

Crop diversity

Higher Temp

rain

rain

rain

rain

Higher Temp

Enhancing Resiliency of Northeast Dairy Farms

Double crop forages: corn silage/rye, rye silage/sorghum sudangrass

In Corn grain, interseed annual ryegrass and clover cover crops
Double-crop winter annual silage with fall manure after corn silage:

**Rye silage dry matter yield after corn silage**

<table>
<thead>
<tr>
<th></th>
<th>Injected manure</th>
<th>Surface broadcast manure</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td><strong>(MT DM ha⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>6.29</td>
<td>6.89</td>
<td>0.24</td>
<td>0.02</td>
</tr>
<tr>
<td>2015</td>
<td>6.85</td>
<td>6.74</td>
<td>0.48</td>
<td>0.16</td>
</tr>
<tr>
<td>2016</td>
<td>8.47</td>
<td>7.8</td>
<td>0.11</td>
<td>0.19</td>
</tr>
<tr>
<td>2017</td>
<td>9.76</td>
<td>8.8</td>
<td>0.30</td>
<td>&gt; 0.01</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>7.74</td>
<td>7.56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Winter annual silage benefits:**
- produces more forage utilizing fall manure nutrients
- good forage quality for dry cows and heifers
- protects soil longer in spring

**Rye silage yield or rye cover crop biomass, corn silage yield, 2017**

<table>
<thead>
<tr>
<th></th>
<th>Rye Biomass</th>
<th>Corn Silage</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(MT DM ha⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rye Silage/Corn Silage</td>
<td>5.69 a</td>
<td>15.61</td>
<td>0.83</td>
</tr>
<tr>
<td>Rye Cover/Corn Silage</td>
<td>4.16 b</td>
<td>17.12</td>
<td>0.83</td>
</tr>
</tbody>
</table>
Enhancing Resiliency of Northeast Dairy Farms

Continuous crops retain soil, manure, promote soil health
Spread production risk over more seasons
Produce more feed and fuel, enhance profitability

Higher Temp

Fall planted winter canola

Soybean

Alfalfa + Grass  Canola
Rye cover c.  Soybean  Rye cover c Corn Sil.  Oats
Alfalfa + Orchardgrass
Continuous cropping (perennials, double-crops, cover crops, interseeded cover crops):

- retain soil and nutrients
- add organic matter, sustain micro-organisms
- improve soil structure, water infiltration
- suppress weeds

Water stable aggregates increase with years in perennial alfalfa and alfalfa and orchardgrass

![Graph showing increase in water stable aggregates (WSA) with years in forage.](image)
Continuous crops

- provide habitat for beneficial organisms
- compete with and suppress weeds

Insect, slug, weed seed predators

Photos: Margaret Douglas; Alfalfa drawing: Kristen Haider
Diverse crop rotation interrupt pest lifecycles
Use IPM
Protect natural enemies, prevent pest resistance

Canola – fuel, feed
Ryelage
Soybeans
Sorghum-sudangrass

Manure N P K

Purchase LESS $:
- Fertilizer
- Herbicide
- Insecticide
Corn European Corn Borer damage has been low and below economic threshold.

**2011 ECB tunnels/plant**

- Control
- Grain
- Forage

**2014 # plants infested with ECB**

- Corn-Soy
- Pest
- Manure

**Avg. # plants with ECB**

- Bt
- Non-Bt

Expected yield loss about 2.5% per tunnel.

**No seed insecticide**
Integrated Weed and Pest Management

- Diversify weed control tactics
- Shift crop planting dates to avoid peak slug activity periods
- Minimize/select insecticides to conserve natural enemies

Herbicide
Insecticide

Reduce pesticide use, selection for pesticide resistance

Purchase LESS:
- Herbicide
- Insecticide

Photos: Margaret Douglas, William Curran, Robert Meinen
Double crop forages: corn silage/rye, rye silage/sorghum sudangrass

More feed and fuel

Continuous cover

Crop diversity

Fall planted winter canola

Enhancing Resiliency of Northeast Dairy Farms

In Corn grain, interseed cover crops

Soybean

IPM for insects
Dairy Farm
65 milk cows and young stock
97 hectares

Grow all dairy feed and forages on more acres
- Manure utilized for more crops, fewer nutrients lost
- Diverse crop rotation interrupts pest lifecycles
- Lower feed costs, profitable Dairy farm over multiple years
- Less energy required

Canola – fuel, feed
Ryelage Soybeans Sorghum-sudangrass

Reduce N P Sediment
loss

Manure N P K

Purchase little feed – poor weather years
System Synergies

- Enhance resilience to climate change
- Reduce soil and nutrient loss, pesticide use, feed costs
- Protect water quality
- Enhance farm profitability
- Promote soil quality
- Reduce selection for pest resistance
Enhancing Resiliency of Northeast Dairy Farms

- More year-round crop production, utilize fall and early spring growing seasons
- Keep soil covered more continuously, to prevent erosion, improve soil health, Utilize manure applications (not just cover crops)
- Conservation Agriculture: Reduce tillage, Produce and retain Crop Residue on Soil, Rotate Crops
- Distribute planting, growth and harvesting operations over more seasons
- Diversify crops for heat tolerance, to interrupt pest lifecycles,
- provide habitat for beneficial species
- Use IPM
- Work with: dairy nutritionists to integrate diverse crops
- farmer networks to promote above strategies
Began evaluating Cropping System 1/20th scale in 2010 on 97 hectares with farm scale equipment
Two diverse 6-year dairy crop rotations
Full crop entry: all phases of rotation planted each year
4 replications
Two Diverse 6 yr No-till Crop Rotations

MANURE ROTATION

PEST ROTATION

• IPM for insect pests
• No Bt traits
• No seed insecticides
• Cover covers & Perennials

Corn-soybean No-till rotation
• Triple-stacked Bt
• Seed insecticide
• Insecticide at planting (Warrior)
• No cover crop
Simulate Dairy Herd: Dairy Production & Nutrition Models

The Virtual Dairy Herd: 65 milking cow herd, dry cows, young stock

Forage Crops:
- alfalfa mixtures
- corn silage
- rye silage
or sorghum
sudangrass

Grain Crops:
- corn
- soybeans
- canola

Evaluate Whole Farm Profitability Over Time
- Whole Farm Enterprise Budget, FINPAC
- Compare to Benchmark PA Dairy Farms

Dairy & Nutrition Models

Crop Yields
Crop Quality

Milk Production
Manure Production

Virginia Ishler
Experienced range of weather
• wet fall (2010, 2011)
• wet springs (2011, 2012)
• dry mid summer year (2011, 2012)

Daily Growing Season
Precipitation (in) 2010-2015

Daily average air temperature (°F)
2010-2015
• low winter temps. (2014, 2015)
• warm spring temps. (2012, 2015)
Manure rotation: to produce enough in poor weather years replaced winter wheat and canola

2010 - 2012

with 3rd year of corn silage/rye silage, sorghum sudangrass

Manure Management Rotation: injection vs. broadcast manure, standard herbicides, IPM for insect pests, and non-Bt corn

2013 - 2015
Two Diverse 6 yr No-till Crop Rotations

**MANURE ROTATION**

**PEST ROTATION**

- IPM for insect pests
- No Bt traits
- No seed insecticides
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Corn European Corn Borer damage has been low and below economic threshold

**2011 ECB tunnels/plant**

- Control: Bt
- Grain: Non-Bt
- Forage: Bt

Expected yield loss about 2.5% per tunnel

**2014 # plants infested with ECB**

- Corn-Soy: Bt
- Pest: Non-Bt
- Manure: Bt

Avg. # plants with ECB

No seed insecticide
Insect predation in corn was higher at night in the diverse rotations each year in June and July. July, 2014, observed the same trend each year.
Corn grain yields: 3 of 5 years were higher in diverse rotations vs. the corn-soy rotation.

**Corn Yields (Bu A⁻¹)**

15.5% Moisture

<table>
<thead>
<tr>
<th>Year</th>
<th>Diverse Rot. (P)</th>
<th>CORN-SOY (C-S)</th>
<th>P vs. C-S (p-value)</th>
<th>Centre Co. or PA State Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>202.40</td>
<td>216.68</td>
<td>0.17</td>
<td>132.5</td>
</tr>
<tr>
<td>2011</td>
<td>163.60 a</td>
<td>129.08 b</td>
<td>0.01</td>
<td>92.7</td>
</tr>
<tr>
<td>2012</td>
<td>159.76</td>
<td>170.04</td>
<td>0.31</td>
<td>132.0</td>
</tr>
<tr>
<td>2013*</td>
<td>193.64</td>
<td>150.18</td>
<td>0.03</td>
<td>147.0</td>
</tr>
<tr>
<td>2014*</td>
<td>192.02</td>
<td>154.43</td>
<td>0.009</td>
<td>-</td>
</tr>
</tbody>
</table>

Different letters (a,b) indicate statistical significance at the p=0.05 level for yield within year & nested in rotation.

*In the diverse rotation corn followed alfalfa & orchardgrass in 2013 and 2014*
<table>
<thead>
<tr>
<th>Best Management Farm</th>
<th>Enhanced Best Management Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover &amp; green manure crops</td>
<td>Small grains for silage</td>
</tr>
<tr>
<td>Alfalfa and alfalfa &amp; orchard grass mix</td>
<td>Only alfalfa &amp; orchard grass mix</td>
</tr>
<tr>
<td>Integrated pest management</td>
<td>Reduced herbicide</td>
</tr>
<tr>
<td>Canola for feed and fuel</td>
<td><strong>Manure Injection</strong> (vs. surface application)</td>
</tr>
<tr>
<td></td>
<td>Canola for feed and fuel</td>
</tr>
</tbody>
</table>

**Cultivating weeds between row crops**

**Small grains (triticale & peas) with alfalfa + orchardgrass vs. pure alfalfa**

**Injecting manure**
## Crop Cost Summary (2011—2014)

<table>
<thead>
<tr>
<th>Crop</th>
<th>BMSH Average</th>
<th>IMRH Average</th>
</tr>
</thead>
</table>
| Corn Silage $/T  
Yield T/A     | $35.93       | $34.79       |
|               | 18.4         | 19.1         |
| All Hay Crops $/T  
Yield T/A     | $59.77       | $70.78       |
|               | 4.15         | 3.72         |
| Corn grain $/bu.  
Yield bu/A     | $1.85        | $1.85        |
|               | 193.7        | 190.2        |
| Soybeans $/bu.  
Yield bu/A     | $5.27        | $5.68        |
|               | 56.5         | 46.3         |
## Summary

### Breakeven Milk Price/cwt

<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMSH Cost per cwt w lbr &amp; mgt</strong></td>
<td>$19.03</td>
<td>$18.21</td>
<td>$19.98</td>
<td>$17.77</td>
<td>$18.75</td>
</tr>
<tr>
<td><strong>IMRH Cost per cwt w lbr &amp; mgt</strong></td>
<td>$19.47</td>
<td>$18.00</td>
<td>$20.22</td>
<td>$16.72</td>
<td>$18.60</td>
</tr>
</tbody>
</table>

### BMSH Dairy Net return over lbr & mgt/cow

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$800-$1000</td>
<td>$396</td>
<td>$216</td>
<td>$254</td>
<td>$1,911</td>
<td>$695</td>
</tr>
</tbody>
</table>

### IMRH Dairy Net return over lbr & mgt/cow

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$800-$1000</td>
<td>$290</td>
<td>$274</td>
<td>$211</td>
<td>$2,255</td>
<td>$758</td>
</tr>
</tbody>
</table>