Integrated Crop and Livestock Management Effects on Soil Health

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If the great successes of American agriculture hide risks to match, what can be done to level out the risks, to reach stability, while preserving productivity? How does research contribute to the problem, or to its solution?

A cursory survey of American agriculture shows a highly successful system, producing bounteous harvests with little effort. Though true to a degree, closer inspection reveals a highly unstable system, easily disrupted by any number of factors, including the weather, insect and disease epidemics, and foreign trade vacillations. The second half of this century has witnessed the concentration of substantial resources toward making a few crops as productive as possible. However, a more visionary strategy would place priority on the design of

2. Despite increased awareness of over-application of fertilizers and pesticides, many surface and underground water sources contain appreciable levels of nitrates, phosphates, and chemicals such as atrazine (7,8).

3. Despite the fact that as much as 80% of the corn grown in the United States is used for animal feed, much manure cannot be readily recycled as fertilizer because livestock and crop operations have been decoupled over the past several decades, leading to nutrient disasters both at feedlots—too much—and on grain farms—too little (2).

4. Despite millions of dollars of public and private research investment, 50 years of chemical control have only made weeds and pests more difficult to control; though chemicals make management simpler in the short run, they invariably create
The Traditional Agricultural Cycle

Human food: animal origin

Livestock Production

Other inputs

Human inputs:
Capital Labor
Services Management

Human food: plant origin

Land/Soil

Grain/Forage

Manure

Water

Crop Production

Other inputs

Human inputs:
Capital Labor
Services Management

Figure 1. The traditional agricultural cycle (Honeyman, 1991).
Note: The average number of commodities per farm is a simple average of the number of farms producing different commodities (corn, sorghum, wheat, oats, barley, rice, soybeans, peanuts, alfalfa, cotton, tobacco, sugar beets, potatoes, cattle, pigs, sheep, and chickens) divided by the total number of farms.
## Production Locus

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Broilers</strong></td>
<td>300,000</td>
<td>384,000</td>
<td>480,000</td>
<td>520,000</td>
<td>681,600</td>
<td>127</td>
</tr>
<tr>
<td><strong>Hogs</strong></td>
<td>1,200</td>
<td>1,880</td>
<td>11,000</td>
<td>23,400</td>
<td>30,000</td>
<td>2,400</td>
</tr>
<tr>
<td><strong>Fattened Cattle</strong></td>
<td>17,532</td>
<td>23,891</td>
<td>38,000</td>
<td>34,494</td>
<td>35,000</td>
<td>100</td>
</tr>
<tr>
<td><strong>Dairy Production</strong></td>
<td>80</td>
<td>100</td>
<td>140</td>
<td>275</td>
<td>570</td>
<td>613</td>
</tr>
</tbody>
</table>

**Production locus (head sold/removed)**

**Production locus (milk cows per farm)**

Note: the production locus measures the size of farm at which half of production came from larger farms and half from smaller farms.
Fig 3. Crop species diversity as effective number of species in 1978, 1987, 1997 and 2012 on a county level basis for the contiguous US.

http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0136580
Source of Nitrogen Delivered to the Gulf of Mexico

- Corn and Soybean Crops
- Other Crops
- Atmospheric Deposition
- Natural Land
- Urban and Population-related Sources
- Pasture and Range

https://water.usgs.gov/nawqa/sparrow/gulf_findings/primary_sources.html
Hog and Pig Sales as Percent of Agriculture Sales, by County, 2012

U.S. = 5.7%

## TABLE 2

**Estimated Amounts of Nitrogen and Phosphorus (metric tons) Excreted Annually by Various Livestock Categories on the North Carolina Coastal Plain, 2000–2001**

<table>
<thead>
<tr>
<th>Animal Category</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swine</td>
<td>101,000</td>
<td>22,700</td>
</tr>
<tr>
<td>Broiler chickens</td>
<td>3,570</td>
<td>1,110</td>
</tr>
<tr>
<td>Other Chickens</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>Turkeys</td>
<td>12,600</td>
<td>3,500</td>
</tr>
<tr>
<td>Cattle</td>
<td>7,000</td>
<td>1,750</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>124,230</strong></td>
<td><strong>29,080</strong></td>
</tr>
</tbody>
</table>
Re-coupling agriculture

- Can we re-couple crop and livestock systems?
- If so, will it help?
- What are the challenges?
What is Integrated Agriculture

- **Integrated Agricultural Production Systems** are agricultural systems with multiple enterprises that interact in space and/or time and the interactions result in a synergistic resource transfer among enterprises.

- **Dynamic-Integrated Agricultural Production Systems** are agricultural production systems with multiple enterprises managed in a dynamic manner that interact in space and/or time and these interactions result in a synergistic resource transfer among enterprises.

Background

- 6000 BC – Crop rotations with legumes in Middle East
- 479 BC – Alfalfa entered Europe from Persia
- 200 BC– 400 AD. Roman 3-field rotation
  - Food-Feed-Fallow
- 1450 AD– Forages included in European rotations
  - Plague
  - Yield Advantages
  - Increased Livestock
**Background**

- Use of perennials lead to new crop rotations.
- Forages were needed for both livestock AND horsepower.
- 1930 26 million ha used for feeding animal traction (Olmstead and Rhode, 2001).
- Post-WW2— Increased mechanized traction and new technology.
Benefits of incorporating forages, diverse crops and livestock into agricultural systems

<table>
<thead>
<tr>
<th>Metric</th>
<th>Impact</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Yield Increase</td>
<td>71% of respondents reported increased yield when annual crops followed forages.</td>
<td>Entz et al. 1995</td>
</tr>
<tr>
<td></td>
<td>Corn in integrated crop/livestock systems yielded 1 Mg ha(^{-1}) more than continuous corn.</td>
<td>Tracy and Zhang 2008</td>
</tr>
<tr>
<td>Enhance Nutrient Cycling</td>
<td>Moving from high external input system to integrated crop livestock system tightens within system nutrient cycling.</td>
<td>Schiere et al. 2002</td>
</tr>
<tr>
<td>Reduce Plant Disease</td>
<td>Rotating between cereal and non-cereal crops reduces soil and residue borne diseases.</td>
<td>Krupinsky et al. 2002</td>
</tr>
<tr>
<td></td>
<td>Including a pulse crop in the rotation enhancing beneficial soil organisms and decreases root diseases.</td>
<td></td>
</tr>
<tr>
<td>Improve Soil Quality</td>
<td>Australian wheat-sheep and Alberta perennial legume-wheat systems are examples of integrated systems that improve soil quality.</td>
<td>Krall and Schuman 1996</td>
</tr>
</tbody>
</table>
Focus

- Selected soil quality parameters
  - Soil bulk density and soil N.
- Impact of grazing.
  - Time and intensity
- Ecosystem services
  - Integrated crop-livestock systems
Bulk Density

- Force of livestock treading 98-192 kPa (Greenwood and McKenzie, 2001)
- Wheeled tractor 74-81 kPa (Blunden et al. 1994)
- Tractors only impact 25% of soil surface (properly inflated tires, Raper 1995).
<table>
<thead>
<tr>
<th>Location</th>
<th>Soil depth (cm)</th>
<th>Soil Bulk Density in Mg m(^{-3})</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sheep</td>
<td></td>
</tr>
<tr>
<td>New South Wales, Australia</td>
<td>0-5</td>
<td>1.17</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 sheep ha(^{-1})</td>
<td>10 sheep ha(^{-1})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uncontrolled mixed grazing</td>
<td></td>
</tr>
<tr>
<td>Sadoré Niger</td>
<td>0-7</td>
<td>1.59</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 sheep ha(^{-1})</td>
<td>125 kg wt ha(^{-1})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cattle</td>
<td></td>
</tr>
<tr>
<td>Mandan, North Dakota, USA</td>
<td>0-5</td>
<td>0.39</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 steers ha(^{-1})</td>
<td>0.4 steers ha(^{-1})</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6 steers ha(^{-1})</td>
<td>0.8 steers ha(^{-1})</td>
</tr>
<tr>
<td>Nunn, Colorado, USA</td>
<td>0-5</td>
<td>1.37</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.37</td>
<td>1.42</td>
</tr>
</tbody>
</table>
Soil N

- Mixed results on soil N.
- In native rangelands, ungrazed rangeland may have the same (Schuman et al. 1999) or more soil N (Frank et al. 1995) than grazed sites.
- In integrated situations, increased available N (Lory et al., 1995; Ma et al., 2003)
Winter Grazing Study

- Evaluation of an integrated system with annual crops.
- Placed in the northern Great Plains.
- Grazing took place in winter.
  - Focus of study to reduce winter feed costs
### Grazed Crops

1. Corn (skip row)
2. BMR Sorghum-sudan/Sweet Clover/Red Clover
3. Oats/Alfalfa/Hairy Vetch/Red Clover

### Ungrazed Treatments

C - Chop Straw/Forage
H - Hay

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>H</td>
<td>H</td>
<td>C</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>
**Grazed Crops**

1. Corn (skip row)
2. BMR Sorghum-sudan/Sweet Clover/Red Clover
3. Oats/Alfalfa/Hairy Vetch/Red Clover

**Ungrazed Treatments**

C - Chop Straw/Forage
H - Hay

High Traffic → Grazed
Low Traffic → Ungrazed
## Results

### Hoof Action (after 3 yr)

<table>
<thead>
<tr>
<th>0-3”</th>
<th>HIGH</th>
<th>LOW</th>
<th>NO</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.09</td>
<td>1.08</td>
<td>1.06</td>
<td>0.9339</td>
</tr>
<tr>
<td>pH</td>
<td>5.89</td>
<td>5.88</td>
<td>5.91</td>
<td>0.9868</td>
</tr>
<tr>
<td>Extr. N (lb/ac)</td>
<td>5.3</td>
<td>4.5</td>
<td>5.1</td>
<td>0.8860</td>
</tr>
<tr>
<td>Extr. P (lb/ac)</td>
<td>7.7</td>
<td>6.2</td>
<td>5.4</td>
<td>0.1664</td>
</tr>
</tbody>
</table>
## Results

### Hoof Action (after 6 yr)

<table>
<thead>
<tr>
<th>0-3”</th>
<th>HIGH</th>
<th>LOW</th>
<th>NO</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>1.01</td>
<td>1.06</td>
<td>1.11</td>
<td>0.7889</td>
</tr>
<tr>
<td>pH</td>
<td>5.99</td>
<td>5.83</td>
<td>6.09</td>
<td>0.5961</td>
</tr>
<tr>
<td>Extr. N (lb/ac)</td>
<td>6.4</td>
<td>7.9</td>
<td>5.4</td>
<td>0.3762</td>
</tr>
<tr>
<td>Extr. P (lb/ac)</td>
<td>7.2</td>
<td>7.3</td>
<td>6.4</td>
<td>0.9655</td>
</tr>
</tbody>
</table>
## Results

### Hoof Action (after 9 yr)

<table>
<thead>
<tr>
<th></th>
<th>HIGH</th>
<th>LOW</th>
<th>NO</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density</strong></td>
<td>1.25</td>
<td>1.14</td>
<td>1.12</td>
<td>0.3744</td>
</tr>
<tr>
<td><strong>(g/cm³)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>5.86</td>
<td>5.80</td>
<td>6.07</td>
<td>0.6848</td>
</tr>
<tr>
<td><strong>Extr. N</strong></td>
<td>15.6</td>
<td>11.5</td>
<td>9.1</td>
<td>0.3193</td>
</tr>
<tr>
<td><strong>(lb/ac)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Extr. P</strong></td>
<td>14.9</td>
<td>13.1</td>
<td>10.1</td>
<td>0.4164</td>
</tr>
<tr>
<td><strong>(lb/ac)</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Under conditions of the swath grazing study, winter grazing appears to have a negligible effect on near-surface soil properties.

Degree of hoof action (High vs. Low vs. None) did not affect soil bulk density, pH, extractable N, and extractable P.
Soil quality measurements were also taken on a grazed perennial pasture. These were improved pastures seeded in early 1980s and on the same soil type.
## Results

### Annual vs. Perennial (after 9 yr)

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>Perenn.</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density (g/cm³)</strong></td>
<td>1.16</td>
<td>1.07</td>
<td>0.2880</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>5.95</td>
<td>6.88</td>
<td>0.5555</td>
</tr>
<tr>
<td><strong>Extr. N (lb/ac)</strong></td>
<td>11.3</td>
<td>0.8</td>
<td>0.0284</td>
</tr>
<tr>
<td><strong>Extr. P (lb/ac)</strong></td>
<td>12.0</td>
<td>4.6</td>
<td>0.0199</td>
</tr>
<tr>
<td><strong>SOC (ton/ac)</strong></td>
<td>10.8</td>
<td>11.4</td>
<td>0.4412</td>
</tr>
</tbody>
</table>
Integrated Crop-Livestock Systems Maintain Soil Quality

Soil measurements were also taken in a grazed perennial pasture

Nine years of detailed soil measurements found...

...thereby reassuring farmers in the northern Great Plains that they can graze crop residue without negatively impacting the soil resource.

Timing of Grazing

Area had been in Intermediate Wheatgrass for 7 years prior to breakout.
Intermediate Wheatgrass had been grazed at 3 different growth stages.
Two different tillage techniques were used in the conversion process.

Techniques were:
1) No-Tillage
2) Minimum-Tillage

Intermediate Wheatgrass was killed using fall and spring Glyphosate applications for the No-Tillage and Minimum-Tillage treatments.
Summary

- No-till appears to be the best option for converting from a perennial system to annual cropping.
- Timing of grazing appears to impact weed populations but the effect was highly variable.

Environmental Services

- Adding diversity to landscapes can enhance some ecosystem services such as biodiversity (Tscharntke et al. 2005).
- Butterfly diversity and species composition has been linked to landscape complexity (Weibull et al. 2000).
- Lack of crop diversity may increase pest pressure and pesticide usage (Meehan et al. 2011).
- Integrated systems that incorporate grasslands should reduce some negative environmental impacts (Lemaire et al. 2013).
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0136580
Ecosystem services

<table>
<thead>
<tr>
<th>State</th>
<th>Colonies</th>
<th>Production x 1000 (lbs honey)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Dakota</td>
<td>490</td>
<td>36260</td>
</tr>
<tr>
<td>South Dakota</td>
<td>290</td>
<td>19140</td>
</tr>
<tr>
<td>Montana</td>
<td>146</td>
<td>12118</td>
</tr>
</tbody>
</table>

Survey of 320 apiaries in North Dakota found that 80% were located in or adjacent to hayland, pastureland or rangeland (Sanderson 2015).
Environmental services

- Negative impacts can also occur
  - Grazing can negatively impact some pollinators (native bumble bees (Kimoto et al. 2012)).
  - Overgrazing or undergrazing can reduce species diversity .
  - Grazing can negatively impact hydrological function (Hendrickson and Sanderson, in press).
In general, integrated crop-livestock systems appear to be neutral to beneficial to soil quality and ecosystem services.

Many negative impacts of integrated systems may be linked to management.
- For example, increased stocking rates impact on soil bulk density.

Grazing animals are powerful tools that through timing or intensity can shape crop or weed responses.
- Targeted grazing concept in range management.

As with any management system, a one-size fits all approach may not be helpful.
However

- Farms are getting larger and more specialized
  - Mid-point of crop production increased from > 600 acres in 1980s to 1100 acres today (MacDonald et al. 2013. ERR-152, USDA-ERS).
  - Mid-point of swine production increased 2400% and dairy production over 600%.
Factors influencing adoption of integrated crop-livestock systems

- Average farmer age in 2012 = 58.
- However, it has been over 50 since 1974.
- Labor

Age distribution of principal farm operators, 1978-2012

Percent of principal farm operators

Source: USDA, National Agricultural Statistics Service, Census of Agriculture, various years. Beginning in 1997, data are adjusted for coverage.
Technology

- Precision Ag
- Drones
- Equipment size
- Economies of scale

What to do?

Producer’s Goals
- Production
- Economic
- Social
- Environmental
- Personal

Exogenous Factors
- Weather/Climate
- Market Conditions
- Government Programs
- New Technology

Management Concerns
- Crop Yield/Quality
- Net Returns
- Pest Management
- Soil/Water/Air Quality
- Resource Conservation

Dynamic-integrated Agricultural System
Economic Viability
Social Acceptability
Hierarchy of Agricultural Systems

- Basic Agricultural Production Systems
- Diverse Agricultural Production Systems
- Dynamic Agricultural Production Systems
- Integrated Agricultural Production Systems
- Dynamic Integrated Agricultural Production Systems

Increasing Complexity → Increasing Sustainability → Increasing Risk
Why?

• The trend is for farms to be less diverse not more diverse.
• This is despite data showing the multiple benefits of integrated systems.
• Integrated systems may require less off-farm inputs but more management inputs.
• Need to include constraints
• Require new collaborations—Economists, Social Scientists, Extension.
  ○ New approaches—Burning cooperatives—Chore cooperatives?
  ○ Regional integration
• Rethink focus demographics.
  ○ Focus on younger producers? Less capital—more management input.
Thank you for your attention

Northern Great Plains Research Laboratory USDA-ARS
https://www.ars.usda.gov/plains-area/mandan-nd/ngprl/