1. Characteristics of the southeastern USA
2. Greenhouse gases (GHGs) and agriculture’s role
3. Management factors affecting GHGs
4. Soil organic C and nutrient cycling results from three on-going pasture experiments in Watkinsville GA
The Southeastern USA

✓ Agricultural production characteristics
  ▪ Fraction of national totals during past 40 years
  ▪ Dotted line is fractional land area of nation in the southeastern USA

USDA-National Agricultural Statistics Service
The Southeastern USA

✓ Agricultural production characteristics (last 100 yr)

USDA-National Agricultural Statistics Service
The Southeastern USA

✓ Agricultural production characteristics (last 100 yr)

USDA-National Agricultural Statistics Service
The Southeastern USA

✓ Agricultural production characteristics (last 100 yr)

USDA-National Agricultural Statistics Service
Agricultural production characteristics (last 100 yr)

USDA-National Agricultural Statistics Service
The Southeastern USA

✓ Agricultural production characteristics (last 100 yr)

USDA-National Agricultural Statistics Service
The Southeastern USA

Value above bar represents total land area (Mha). Data from USDA-NASS (1997).
Characteristics of Humid Grazing Lands

Predominantly in the eastern half of the USA and ca. 300 km of West Coast

Precipitation > 600 mm yr

National Atlas of the United States
Characteristics of Humid Grazing Lands

- Generally acidic soils
- Introduced plant species with high productivity potential and high forage quality
- Species that respond to inputs of fertilizer and management variables
- Utilization of forage is diverse, including intensive rotation, extensive, and haying
- In the southeastern USA, nearly year-round grazing potential (i.e., both warm- and cool-season)
Greenhouse Gases

✔ What are they?

- Carbon dioxide \((\text{CO}_2)\)
- Methane \((\text{CH}_4)\)
- Nitrous oxide \((\text{N}_2\text{O})\)
Greenhouse Gases

Why are they important?

- Increasing concentration in the atmosphere since 1750 (Intergovernmental Panel on Climate Change, 2001)
  - CO₂ – 31% increase
  - CH₄ – 151% increase
  - N₂O – 17% increase

- Cause radiative forcing of the atmosphere, which could alter global temperature and ecosystem functioning

- Can be manipulated by type of land management
Agricultural Role in GHG Emission

✓ In the USA, <10% of total emission

Source of emission (global warming potential)

CO₂ (1)
- soil cultivation
- fuel use

CH₄ (21)
- anaerobic soil (rice)
- enteric fermentation
- livestock waste

N₂O (310)
- fertilization
- livestock waste

Regional Comparisons
North America

North America divided into 5 regions
-------------------
Northwest
Southwest
Northeast
Central
Southeast
Regional Comparisons
North America

Greenhouse Gas Contributions and Mitigation Potential in Agricultural Regions of North America
Special issue (mid 2005)

1. Introduction, Franzluebbers AJ, Follett RF
2. DAYCENT model analysis of soil N\textsubscript{2}O…Del Grosso SJ, Mosier AR, Parton WJ, Ojima DS
3. Northwestern region…Liebig MA, Morgan JA, Reeder JD, Ellert BH, Gollany HT, Schuman GE
5. Central region…Johnson JMF, Reicosky DC, Allmaras RR, Sauer TJ, Venterea RT, Dell CJ
6. Southwestern region…Martens DA, Emmerich W, McLain JET, Johnsen TN Jr
7. Southeastern USA…Franzluebbers AJ
8. …irrigated Vertisol in central MexicoMartens DA, Emmerich W, McLain JET, Johnsen TN Jr
9. Research and implementation needs…Follett RF, Shafer SR, Jawson MD, Franzluebbers AJ
### Regional Comparisons
#### North America

<table>
<thead>
<tr>
<th>Management</th>
<th>NW</th>
<th>NE</th>
<th>C</th>
<th>SW</th>
<th>SE</th>
<th>Conant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil organic C sequestration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N fertilizer</td>
<td>0.09</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>0.18</td>
</tr>
<tr>
<td>Conversion of crop land to grassland</td>
<td>0.94</td>
<td>.</td>
<td>0.56</td>
<td>0.32</td>
<td>1.03</td>
<td>1.01</td>
</tr>
<tr>
<td>Grazed vs ungrazed Grassland</td>
<td>0.16</td>
<td>.</td>
<td>.</td>
<td>-0.03</td>
<td>0.76</td>
<td>0.35</td>
</tr>
<tr>
<td>(N_2O) emission (in C equivalence)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All agriculture</td>
<td>-0.38</td>
<td>-0.41</td>
<td>.</td>
<td>-0.91</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>Grass systems</td>
<td>-0.08</td>
<td>-0.15</td>
<td>.</td>
<td>-0.91</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>(\text{DAYCENT (Del Gross et al.)})</td>
<td>-0.24</td>
<td>-0.25</td>
<td>-0.36</td>
<td>-0.32</td>
<td>-0.36</td>
<td></td>
</tr>
</tbody>
</table>
Agricultural Mitigation Strategies

✓ Increase soil organic carbon sequestration
  ▪ Conversion of land to less disturbed usage
  ▪ Conservation tillage
  ▪ Pasture development

✓ Reduce fossil fuel use
  ▪ Tractor time
  ▪ Grain drying
  ▪ Irrigation

✓ Reduce nitrogen fertilizer saturation
  ▪ Reduce opportunities for nitrous oxide emission

✓ Increase cropping intensity
  ▪ Sequester more C per unit of input costs
Management Factors Affecting Soil Organic C

- Land use
  - Forest
  - Grass
  - Crops
- Forage type
  - Cool or warm season
  - Annual or perennial
  - Endophyte
- Fertilization
  - Inorganic N-P-K
  - Animal manures
- Utilization
  - Hay
  - CRP
  - Grazing pressure
Land Use

✓ Conversion of forest to conventionally tilled cropland can reduce SOC by >50%
Land Use

✓ Under forest and grass, soil organic C is typically stratified with depth.

✓ Below 0.5 m, soil organic C is typically <5 g kg⁻¹, except in high-clay-content soils.

How important are grasslands to C sequestration compared with other land uses?

<table>
<thead>
<tr>
<th>Land use</th>
<th>Land area $10^6$ km$^2$</th>
<th>Above-ground C stocks kg m$^{-2}$</th>
<th>Soil C stocks kg m$^{-2}$</th>
<th>Total C stocks kg m$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical/temperate forest</td>
<td>28</td>
<td>9.7</td>
<td>11.3</td>
<td>21.0</td>
</tr>
<tr>
<td>Cropland</td>
<td>8</td>
<td>0.2</td>
<td>8.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Tropical/ temperate grassland</td>
<td>35</td>
<td>2.1</td>
<td>16.0</td>
<td>18.1</td>
</tr>
</tbody>
</table>

From Intergovernmental Panel on Climate Change Special Report on Land Use, Land-Use Change and Forestry
## Land Use

<table>
<thead>
<tr>
<th>Study</th>
<th>Depth</th>
<th>Forest</th>
<th>Grass</th>
<th>Crop</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Texas, Laws and Evans (1949), Potter et al. (1999)</td>
<td>30</td>
<td>--</td>
<td>88 ± 18</td>
<td>57 ± 8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AL-AR-FL-GA-LA-MS-NC-SC-TX-VA, McCracken (1959)</td>
<td>25</td>
<td>31 ± 12</td>
<td>31 ± 16</td>
<td>23 ± 15</td>
<td>0.04</td>
</tr>
<tr>
<td>Maryland, Islam and Weil (2000)</td>
<td>15</td>
<td></td>
<td>32 ± 10</td>
<td>20 ± 7</td>
<td>0.01</td>
</tr>
<tr>
<td>Alabama, Fesha et al. (2002), Torbert et al. (2004)</td>
<td>25 ± 6</td>
<td>60 ± 21</td>
<td>48 ± 26</td>
<td>34 ± 8</td>
<td>0.03</td>
</tr>
<tr>
<td>Mississippi, Georgia, Rhoton and Tyler (1990), Franzluebbers et al. (2000)</td>
<td>25 ± 7</td>
<td>47 ± 2</td>
<td>38</td>
<td>22 ± 6</td>
<td>0.08</td>
</tr>
<tr>
<td>Mean</td>
<td>24 ± 6</td>
<td>49.9 a</td>
<td>47.4 a</td>
<td>31.1 b</td>
<td></td>
</tr>
</tbody>
</table>

Pastures

✓ Grass establishment affects soil organic C

**Effect of grass establishment**

- Number of studies: 12
- Duration of comparison (yr): 15 ± 17
- SOC sequestration (Mg ha\(^{-1}\) yr\(^{-1}\)): 1.03 ± 0.90

Rate of SOC sequestration was 2.5 times greater than with NT cropping

Forage Type
Cool- vs Warm- Season Grasses

Soil organic C sequestration rate during 25 years

- 'K-31' Tall fescue: 0.78 Mg ha\(^{-1}\) yr\(^{-1}\)
- 'Coastal' bermudagrass: 0.26 Mg ha\(^{-1}\) yr\(^{-1}\)

Different opportunities for growth during the year.

**Fertilization**

✓ Poultry manure affects soil organic C

<table>
<thead>
<tr>
<th>Effect of manure application</th>
<th>Without</th>
<th>With</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-yr studies (n=6)</td>
<td>19.8 ± 8.9</td>
<td>19.6 ± 8.4</td>
</tr>
<tr>
<td>11 ± 8-yr studies (n=8)</td>
<td>30.6 ± 11.4</td>
<td>36.8 ± 10.6</td>
</tr>
<tr>
<td>SOC sequestration for all (Mg ha⁻¹ yr⁻¹)</td>
<td>0.26 ± 2.15</td>
<td></td>
</tr>
<tr>
<td>SOC sequestration for &gt;2-yr studies</td>
<td>0.72 ± 0.67</td>
<td></td>
</tr>
</tbody>
</table>

✓ Conversion of C in poultry litter to SOC was 17 ± 15%.
✓ Manure application transfers C from one land to another.

Fertilization
Inorganic vs Organic Source

From a compilation of available literature around the world (Conant et al., 2001, Ecol. Appl. 11:343-355), SOC sequestration was compared between inorganic and organic fertilization.

<table>
<thead>
<tr>
<th>Management</th>
<th>Rate of SOC Sequestration (Mg ha⁻¹ yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic fertilizer</td>
<td>0.29</td>
</tr>
<tr>
<td>Organic fertilizer</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Fertilization  
Rate of N-P-K Application

Long-term effect of low (134-15-56 kg N-P-K ha\(^{-1}\) yr\(^{-1}\)) versus high (336-37-136 kg N-P-K ha\(^{-1}\) yr\(^{-1}\)) fertilization of tall fescue pastures on SOC

At the end of 15 years

<table>
<thead>
<tr>
<th>Soil Depth</th>
<th>Fertilizer Rate</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>----</td>
<td>Mg ha(^{-1}) ---</td>
</tr>
<tr>
<td>0 to 2.5</td>
<td></td>
<td>10.2</td>
<td>10.9</td>
</tr>
<tr>
<td>2.5 to 7.5</td>
<td></td>
<td>11.0</td>
<td>&lt; 11.8</td>
</tr>
<tr>
<td>7.5 to 15</td>
<td></td>
<td>11.0</td>
<td>&lt; 11.7</td>
</tr>
<tr>
<td>15 to 30</td>
<td></td>
<td>12.8</td>
<td>13.1</td>
</tr>
<tr>
<td>0 to 30</td>
<td></td>
<td>45.0</td>
<td>&lt; 47.6</td>
</tr>
</tbody>
</table>

At the end of 20 years

<table>
<thead>
<tr>
<th>Soil Depth</th>
<th>Fertilizer Rate</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>----</td>
<td>Mg ha(^{-1}) ---</td>
</tr>
<tr>
<td>0 to 3</td>
<td></td>
<td>11.7</td>
<td>13.1</td>
</tr>
<tr>
<td>0 to 6</td>
<td></td>
<td>19.1</td>
<td>20.8</td>
</tr>
<tr>
<td>0 to 12</td>
<td></td>
<td>29.2</td>
<td>&lt; 31.3</td>
</tr>
<tr>
<td>0 to 20</td>
<td></td>
<td>37.6</td>
<td>&lt; 40.3</td>
</tr>
</tbody>
</table>

Schnabel et al. (2001) In: Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect
Fertilization
Nitrogen and Phosphorus Application

From a compilation of available literature around the world (Conant et al., 2001, Ecol. Appl. 11:343-355), SOC sequestration was assessed with **improved fertilization** (i.e., a higher N and/or P rate) to improve forage production.

<table>
<thead>
<tr>
<th>Biome</th>
<th>Mean Annual Soil C Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Based on Concentration</td>
</tr>
<tr>
<td><strong>More aridic</strong></td>
<td></td>
</tr>
<tr>
<td>Desert</td>
<td>NA</td>
</tr>
<tr>
<td>Grassland</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>More udic</strong></td>
<td></td>
</tr>
<tr>
<td>Woodland</td>
<td>4.0</td>
</tr>
<tr>
<td>Forest</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Forage Utilization
Grazed vs Hayed

✓ Long-term pasture survey (15- to 19-year old fields, 3 each)

Soil Organic Carbon (g · kg\(^{-1}\))

Soil Depth (cm)

Carbon Stock (Mg · ha\(^{-1}\))

Surface residue

- 1.2
- 1.8

Soil (0-20 cm)

- 31.1
- 38.0

Difference

- 7.5

Mg ha\(^{-1}\) yr\(^{-1}\)

Forage Utilization
Grazed vs Ungrazed

From a compilation of available literature around the world (Conant et al., 2001, Ecol. Appl. 11:343-355), SOC sequestration was assessed with moderate grazing pressure compared with less than optimal grazing pressure.

<table>
<thead>
<tr>
<th>Biome</th>
<th>Mean Annual Soil C Change (%)</th>
<th>Based on Concentration</th>
<th>Based on Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>More aridic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desert</td>
<td>-0.1</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Shrubland</td>
<td>1.8</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td>0.0</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td><strong>More udic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Woodland</td>
<td>8.0</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>0.9</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Rainforest</td>
<td>7.3</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>
Forage Utilization
Animal Behavior

At the end of 8 to 15 years of grazing K-31 tall fescue

Forage Utilization
Methane Emission

ca. 70% of total CH₄ emission in USA from agriculture

Assumptions:
0.15 ± 0.08 kg CH₄ head⁻¹ d⁻¹ (Harper et al., 1999; J. Anim. Sci. 77:1292-1401)
19 Mha of pasture land (USDA-NASS, 1997)
12 million head of cattle (USDA-NASS, 1997)

Resulting in:
0.62 head ha⁻¹ 34 kg CH₄ ha⁻¹ yr⁻¹
0.37 to 1.20 Mg CO₂-C equivalent ha⁻¹ yr⁻¹
Nitrous oxide

- Limited data available

<table>
<thead>
<tr>
<th>Study</th>
<th>Control</th>
<th>Poultry Litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal Plain (AL)</td>
<td>6.3</td>
<td>4.9</td>
</tr>
<tr>
<td>Piedmont (GA)</td>
<td>0.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Cumberland Plateau (TN)</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Thornton et al. (1998) Atmos. Environ. 32:1623-1630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tennessee Valley (AL)</td>
<td>0.5</td>
<td>3.9</td>
</tr>
<tr>
<td>urea 3.0  composted 1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Athens GA (cropping system)</td>
<td>CT 579</td>
<td>NT 505</td>
</tr>
<tr>
<td>Dillard GA (riparian forest)</td>
<td>grazed 25</td>
<td>ungrazed 24</td>
</tr>
</tbody>
</table>
✓ Methane

- Flux estimates in other regions indicate potential for soil with high organic matter to act as a sink for CH₄
- No data on soil CH₄ uptake in the southeastern USA

Harper et al. (2000) J. Environ. Qual. 29:1356-1365
Cordele GA (swine confinement, micrometeorological assessment)

<table>
<thead>
<tr>
<th>Lagoon</th>
<th>Total gas flux</th>
<th>N₂</th>
<th>CO₂</th>
<th>N₂O</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha⁻¹ d⁻¹</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>First (3.5 ha)</td>
<td>159</td>
<td>15</td>
<td>5</td>
<td>0</td>
<td>79</td>
</tr>
<tr>
<td>Second (1.3 ha)</td>
<td>21</td>
<td>54</td>
<td>2</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>Third (3.5 ha)</td>
<td>20</td>
<td>59</td>
<td>1</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td>Fourth (1.3 ha)</td>
<td>17</td>
<td>69</td>
<td>1</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>
On-Going Studies in Watkinsville GA

✓ Salem Road grazing study, Farmington GA
✓ Phase 1: 1994-1998, ‘Coastal’ bermudagrass
✓ Phase 2: 1999-2005, interseeded ‘Georgia 5’ tall fescue
✓ 4 harvest regimes
  ▪ Hayed
  ▪ Low forage mass
  ▪ High forage mass
  ▪ Unharvested

✓ 3 fertilization regimes (200 kg N ha⁻¹ yr⁻¹)
  ▪ Inorganic only
  ▪ Clover+inorganic
  ▪ Broiler litter

✓ 3 replications

Phase 2
Salem Road Grazing Study

✓ Grazed paddocks

- 0.7 ha each
- permanent shade/water near top of landscape in each paddock
- Angus yearling steers from May to October (140-d grazing period each year)
- Stocking density adjusted every 28 days to target forage availability
Salem Road Grazing Study

✓ Exclosures

Hayed exclosures
- 100 m²
- Forage cut and removed every 28 days

Unharvested exclosures
- 100 m²
- Forage cut in October and left in place
- CRP simulation
Salem Road Grazing Study

Fertilization Source Effect

Impact
Fertilizer sources were equally effective in sequestering soil organic C

Salem Road Grazing Study

Fertilization Source Effect

Mean yearly change (kg · ha⁻¹ · yr⁻¹)

Total Soil Nitrogen (kg · ha⁻¹)

Years of Management

From Franzluebbers et al. (2001)
Salem Road Grazing Study

Fertilization Source Effect

From Franzluebbers et al. (2002)
Salem Road Grazing Study

Harvest Strategy Effect

Impact
Grazed pastures sequestered more than twice the quantity of soil organic C as ungrazed forage systems.

Salem Road Grazing Study
Harvest Strategy Effect

From Franzluebbers et al. (2001)
Salem Road Grazing Study

Harvest Strategy Effect

From Franzluebbers et al. (2002)
Salem Road Grazing Study

Harvest Strategy Effect

From Franzluebbers et al. (2001)
and unpublished data.
Salem Road Grazing Study

Relationship between soil bulk density and soil organic C of 0- to 2-cm depth during first five years

Water (cm) held at saturation capacity to a depth of 20 cm

\[ BD = 0.81 + 2.36 \exp(-0.067 \cdot SOC) \]
\[ r^2 = 0.88, n = 180 \]

From Franzluebbers et al. (2001)
Salem Road Grazing Study

Harvest Strategy Effect

Vertical distribution of soil organic C

From Franzluebbers et al. (2001)
### Salem Road Grazing Study

**Harvest Strategy Effect**

<table>
<thead>
<tr>
<th>Vertical distribution of organic C</th>
<th>Carbon stock (Mg · ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface residue</td>
<td></td>
</tr>
<tr>
<td>0-3 cm</td>
<td>2.5 a</td>
</tr>
<tr>
<td>3-6 cm</td>
<td>10.6 b</td>
</tr>
<tr>
<td>6-12 cm</td>
<td>6.8 ab</td>
</tr>
<tr>
<td>12-20 cm</td>
<td>12.3 a</td>
</tr>
<tr>
<td>12-20 cm</td>
<td>9.2 a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Unharvested</th>
<th>Low grazing pressure</th>
<th>High grazing pressure</th>
<th>Hayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface residue</td>
<td>2.5 a</td>
<td>2.1 b</td>
<td>1.5 c</td>
<td>0.9 d</td>
</tr>
<tr>
<td>0-3 cm</td>
<td>10.6 b</td>
<td>12.7 a</td>
<td>13.0 a</td>
<td>9.6 c</td>
</tr>
<tr>
<td>3-6 cm</td>
<td>6.8 ab</td>
<td>7.4 a</td>
<td>7.1 a</td>
<td>6.3 b</td>
</tr>
<tr>
<td>6-12 cm</td>
<td>12.3 a</td>
<td>12.6 a</td>
<td>12.2 a</td>
<td>11.7 a</td>
</tr>
<tr>
<td>12-20 cm</td>
<td>9.2 a</td>
<td>10.1 a</td>
<td>9.2 a</td>
<td>9.7 a</td>
</tr>
<tr>
<td>12-20 cm</td>
<td>41.4 b</td>
<td>44.9 a</td>
<td>42.9 ab</td>
<td>38.1 c</td>
</tr>
</tbody>
</table>

From Franzluebbers et al. (2001)  
Fate of N in management systems

Of the average N applied in these systems (214 kg N · ha⁻¹ · yr⁻¹), the following budget could be constructed:

<table>
<thead>
<tr>
<th>System</th>
<th>Residue</th>
<th>Soil 0-6 cm</th>
<th>Soil 6-20 cm</th>
<th>Hay</th>
<th>Animal gain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unharvested</td>
<td>12</td>
<td>3</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Low grazing pressure</td>
<td>10</td>
<td>32</td>
<td>31</td>
<td>0</td>
<td>3</td>
<td>76</td>
</tr>
<tr>
<td>High grazing pressure</td>
<td>8</td>
<td>48</td>
<td>23</td>
<td>0</td>
<td>3</td>
<td>82</td>
</tr>
<tr>
<td>Hayed</td>
<td>4</td>
<td>-5</td>
<td>12</td>
<td>57</td>
<td>0</td>
<td>68</td>
</tr>
</tbody>
</table>

% of applied N

At the end of 5 years of grazing Coastal bermudagrass in the summer

Standing Stock of C (Mg · ha⁻¹)

Surface residue

Total C

Unpublished data
Salem Road Grazing Study

Spatial distribution of total soil N within paddocks

Total Soil Nitrogen (kg ha\(^{-1}\))

Distance from Shade (m)

- 0-6 cm

- Inorganic
- Clover + inorganic
- Broiler litter

Unpublished data
Salem Road Grazing Study

Spatial distribution of extractable soil P within paddocks

Mehlich-I Extractable Soil P (mg·kg⁻¹)

Distance from Shade (m)

Salem Road Grazing Study

Vertical distribution of extractable soil P with depth

From Franzluebbers et al. (2002)
Salem Road Grazing Study

Variation in ground cover

May 2001

Distance from Shade / Water

Near

Mid

Far

Low grazing pressure

High grazing pressure

TF - tall fescue, CBG - ‘Coastal’ bermudagrass

Unpublished data
Salem Road Grazing Study

Variation in ground cover due to harvest strategy

Evaluated May 2001 following interseeding of tall fescue into bermudagrass in Autumn 1998

Planted grasses
TF = Tall fescue
CBG = Coastal bermudagrass

Unpublished data following interseeding of tall fescue into bermudagrass in Autumn 1998

Variation in ground cover due to harvest strategy
Salem Road Grazing Study

During the first five years of bermudagrass management . . .

Fertilization strategy resulted in:

- Equal changes in soil organic C (~0.9 Mg · ha⁻¹ · yr⁻¹)
- Equal changes in total soil N (104 kg · ha⁻¹ · yr⁻¹)
- Greater change in extractable soil P with broiler litter (11 kg · ha⁻¹ · yr⁻¹) than with inorganic or clover + inorganic fertilization (1 kg · ha⁻¹ · yr⁻¹)
Salem Road Grazing Study

During the first five years of bermudagrass management . . .

Harvest strategy resulted in:

- Greater change in soil organic C with grazing (1.4 Mg·ha⁻¹·yr⁻¹) compared with haying (0.3 Mg·ha⁻¹·yr⁻¹) and unharvested management (0.7 Mg·ha⁻¹·yr⁻¹)

- Greater change in total soil N with grazing (156 kg·ha⁻¹·yr⁻¹) compared with haying (30 kg·ha⁻¹·yr⁻¹) and unharvested management (73 kg·ha⁻¹·yr⁻¹)

- Greater change in extractable soil P with grazing (4.4 kg·ha⁻¹·yr⁻¹) compared with haying and unharvested (−1.5 kg·ha⁻¹·yr⁻¹)

- Few differences in soil properties, including compaction, between low and high grazing pressure variables
Salem Road Grazing Study

During the first five years of bermudagrass management . . .

Soil properties became spatially variable:

- **By depth**, where concentrations of nutrients accumulated near the soil surface, especially within the surface 6 cm

- **Due to animal behavior**, where nutrients accumulated near shade and water sources as a result of more time spent at these locations
On-Going Studies in Watkinsville GA

✓ Dawson Field grazing study, Watkinsville, Hog Mountain Rd
✓ 2002-2004, ‘Jesup’ tall fescue
✓ 3 endophyte associations
  ▪ Wild-type endophyte
  ▪ Max-Q endophyte (low ergot alkaloid)
  ▪ No endophyte
✓ 2 fertilization regimes (180 kg N ha\(^{-1}\) yr\(^{-1}\))
  ▪ Inorganic
  ▪ Broiler litter
✓ 2 replications
✓ +2 hayed, Max-Q, inorganically fertilized pastures
Dawson Field Grazing Study

What is the tall fescue-endophyte association?

✓ The fungus, *Neotyphodium coenophialum*, growing within the herbage of tall fescue, *Festuca arundinacea*.
✓ A mutualistic relationship, whereby the fungus receives:
  • energy
  • nutrients
  • shelter
  • means of propagation
✓ And the fungus provides the plant with:
  • various alkaloids: N-containing ring structures that deter insects and overgrazing
  • drought tolerance
  • persistence

“Endo” living within, “phyte” plant
Why study the tall fescue-endophyte association?

- Tall fescue is still the most widely adapted, cool-season perennial forage in the southeastern USA.
- Farm animals grazing endophyte-infected tall fescue variably develop animal health disorders (fescue foot, fat necrosis, fescue toxicosis). Strategies to overcoming these disorders have not been universally understood by scientists, developed by industry, nor accepted by producers.
- Two important developments have prompted our current investigations:
  - “Novel” endophytes that do not produce ergot alkaloids (responsible for fescue toxicosis) have been identified and placed into improved plant cultivars.
  - Soil carbon sequestration under endophyte-infected was found greater than under uninfected tall fescue.
Previous research illustrated that soil organic C accumulated in response to endophyte.

Specific mineralization of SOC (mg CO₂-C g⁻¹ SOC)

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>98</td>
<td>** 78</td>
</tr>
<tr>
<td>43</td>
<td>** 38</td>
</tr>
<tr>
<td>26</td>
<td>* 23</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

Dawson Field Grazing Study

14 paddocks (2.5 acre each) established as individual water catchments in 2002
- 12 grazed + 2 hayed

3 tall fescue-endophyte associations
- ‘Jesup’ endophyte-free (E-Free)
- ‘Jesup’ Max Q endophyte (E-MaxQ)
- ‘Jesup’ wild endophyte (E-Wild)

2 fertilization regimes (80 lb N/a, 2x/yr)
- inorganic
- broiler litter
2 reps
Grazed by yearling Angus heifers
Dawson Field Grazing Study

Time of grazing

2002

(-----Winter-----) (------Spring-----) (----Summer----) (-----Autumn----)

2003

2004
## Dawson Field Grazing Study

<table>
<thead>
<tr>
<th>Season</th>
<th>Days with grazing (%)</th>
<th>Average daily gain (kg Ad⁻¹)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter (Jan-Mar)</td>
<td>26</td>
<td>1.13</td>
<td>1.21</td>
<td>&gt;</td>
<td>0.88</td>
</tr>
<tr>
<td>Spring (Apr-Jun)</td>
<td>79</td>
<td>0.90</td>
<td>0.88</td>
<td>&gt;</td>
<td>0.55</td>
</tr>
<tr>
<td>Summer (Jul-Sep)</td>
<td>61</td>
<td>0.64</td>
<td>0.66</td>
<td></td>
<td>0.56</td>
</tr>
<tr>
<td>Autumn (Oct-Dec)</td>
<td>76</td>
<td>0.69</td>
<td>&lt;</td>
<td>0.80</td>
<td>&gt;</td>
</tr>
<tr>
<td>Yearly</td>
<td>60</td>
<td>0.84</td>
<td>&lt;</td>
<td>0.89</td>
<td>&gt;</td>
</tr>
</tbody>
</table>
## Dawson Field Grazing Study

<table>
<thead>
<tr>
<th>Season</th>
<th>Stocking rate (head $\text{Aha}^{-1}$)</th>
<th>Live-weight gain (kg $\text{Aha}^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>E-Free</td>
</tr>
<tr>
<td>Winter (Jan-Mar)</td>
<td>1.1</td>
<td>97</td>
</tr>
<tr>
<td>Spring (Apr-Jun)</td>
<td>3.3</td>
<td>254</td>
</tr>
<tr>
<td>Summer (Jul-Sep)</td>
<td>2.1</td>
<td>103</td>
</tr>
<tr>
<td>Autumn (Oct-Dec)</td>
<td>3.3</td>
<td>222</td>
</tr>
<tr>
<td>Yearly</td>
<td>2.4</td>
<td>676</td>
</tr>
</tbody>
</table>
Dawson Field Grazing Study

**Previous research:**
Field sampling of tall fescue paddocks at the end of 20 years

<table>
<thead>
<tr>
<th>Soil component</th>
<th>Low Fertilizer</th>
<th>High Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E-</td>
<td>E+</td>
</tr>
<tr>
<td>Whole soil</td>
<td>37.2</td>
<td>38.0</td>
</tr>
<tr>
<td>Large macroaggregates</td>
<td>26.9</td>
<td>29.6</td>
</tr>
<tr>
<td>Small macroaggregates</td>
<td>14.7</td>
<td>14.8</td>
</tr>
<tr>
<td>Microaggregates</td>
<td>3.4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

## Dawson Field Grazing Study

**Previous research:**
Biologically active pools of soil C and N in long-term field study

<table>
<thead>
<tr>
<th>Soil component</th>
<th>Low Fertilizer</th>
<th>High Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E-</td>
<td>E+</td>
</tr>
<tr>
<td>Particulate (&gt;0.05 mm)</td>
<td>410</td>
<td>390</td>
</tr>
<tr>
<td>Microbial biomass</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>Mineralizable</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>Particulate (&gt;0.05 mm)</td>
<td>660</td>
<td>580</td>
</tr>
<tr>
<td>Mineralizable</td>
<td>43</td>
<td>41</td>
</tr>
</tbody>
</table>

---

To directly test whether soil microbial activity might be inhibited by compounds in the tall fescue-endophyte association, a laboratory decomposition study was performed with leaves from E- and E+ pastures.

Although biologically active soil C pools were negatively affected by endophyte infection as observed in sampling of field soils, biologically active soil N pools were enhanced with endophyte infection.
Decomposition of ergot alkaloids in tall fescue leaves incubated with soil was rapid.
Dawson Field Grazing Study

If ergot alkaloids decomposed so rapidly during short-term incubation, soil exposed to long-term management of E+ tall fescue would probably not have evidence of ergot alkaloids.

<table>
<thead>
<tr>
<th>Soil fraction</th>
<th>E-</th>
<th>E+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil sediment</td>
<td>12</td>
<td>*</td>
</tr>
<tr>
<td>Coarse fraction</td>
<td>2.2</td>
<td>*</td>
</tr>
<tr>
<td>Water extract</td>
<td>0.22*</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Discovery of significant “background” ergot alkaloid concentration in soil under 10-year-old pasture suggests that other environmental consequences of wild-type endophyte infection could occur, possibly in water runoff.

Dawson Field Grazing Study

A next step – Constituents in water runoff (nutrients, bacteria, ergot alkaloids...)

[Images of field and equipment setup]
On-Going Studies in Watkinsville GA

- Pasture-Crop Rotation study, Watkinsville, Govt. Station Rd.
- 1982-2002, tall fescue-endophyte associations
- 2002-2004, grain cropping with cover crops
- 2 cropping systems
  - Summer grain – winter cover crop (sorghum-rye)
  - Winter grain – summer cover crop (wheat – pearl millet)
- 2 tillage regimes
  - Conventional tillage
  - No tillage
- 2 cover crop management regimes
  - Unutilized
  - Grazed by cattle
- 4 replications
Pasture-Crop Rotation Study

Cow/calf grazing
Pasture-Crop Rotation Study

✓ Summer grain – winter cover crop
Pasture-Crop Rotation Study

✓ Winter grain – summer cover crop

![Graph showing precipitation and evapotranspiration over a year with images of winter wheat, pearl millet grazed by cattle, and ungrazed pearl millet.]
### Pasture-Crop Rotation Study

**Summer Grain – Winter Cover Crop**

<table>
<thead>
<tr>
<th>Crop component</th>
<th>Unutilized</th>
<th>Grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rye stover</td>
<td>7.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Sorghum grain</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Sorghum stover</td>
<td>3.7</td>
<td>3.0</td>
</tr>
</tbody>
</table>

---

*Unpublished data*
### Pasture-Crop Rotation Study

**Summer Grain – Winter Cover Crop**

<table>
<thead>
<tr>
<th>Crop component</th>
<th>CT</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum grain</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>Sorghum stover</td>
<td>2.5</td>
<td>&lt;&lt;</td>
</tr>
<tr>
<td>Rye stover (ungrazed)</td>
<td>7.0</td>
<td>&lt;</td>
</tr>
</tbody>
</table>

Unpublished data

<table>
<thead>
<tr>
<th>Animal component</th>
<th>CT</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stocking rate (head ha⁻¹)</td>
<td>6.6</td>
<td>&lt;</td>
</tr>
<tr>
<td>Animal gain (kg ha⁻¹)</td>
<td>294</td>
<td>&lt;</td>
</tr>
<tr>
<td>Calf daily gain (kg head⁻¹ d⁻¹)</td>
<td>1.02</td>
<td>1.09</td>
</tr>
</tbody>
</table>
## Pasture-Crop Rotation Study
### Winter Grain – Summer Cover Crop

<table>
<thead>
<tr>
<th>Crop component</th>
<th>Unutilized</th>
<th>Grazed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millet stover</td>
<td>10.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>2.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Wheat stover</td>
<td>1.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

---

*Unpublished data*
## Pasture-Crop Rotation Study

### Winter Grain – Summer Cover Crop

<table>
<thead>
<tr>
<th>Crop component</th>
<th>CT</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mg ha⁻¹</strong></td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td>Wheat stover</td>
<td>1.1</td>
<td>&lt; 1.3</td>
</tr>
<tr>
<td>Millet stover (ungrazed)</td>
<td>8.9</td>
<td>&lt;&lt; 12.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animal component</th>
<th>CT</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>head ha⁻¹</strong></td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Stocking rate</td>
<td>7.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Animal gain</td>
<td>404</td>
<td>433</td>
</tr>
<tr>
<td>Calf daily gain (kg head⁻¹ d⁻¹)</td>
<td>0.93</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Unpublished data

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*Mg ha⁻¹*
Pasture-Crop Rotation Study

Initially high surface C

Following inversion tillage, soil organic C became relatively uniformly distributed with depth

Soil organic C with NT was greater than with CT in the surface 6 cm, but lower than with CT below 12 cm
## Pasture-Crop Rotation Study

<table>
<thead>
<tr>
<th>Time</th>
<th>Soil</th>
<th>Surface Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>NT</td>
</tr>
<tr>
<td>0-20-cm depth</td>
<td>-------------------</td>
<td>Mg C ha(^{-1})</td>
</tr>
<tr>
<td>Initiation</td>
<td>37.9</td>
<td>39.2</td>
</tr>
<tr>
<td>End of 1 yr</td>
<td>33.2 (&lt;&lt;) 38.9</td>
<td>0.2 (&lt;&lt;) 2.2</td>
</tr>
<tr>
<td>End of 2 yr</td>
<td>33.9 (&lt;&lt;) 40.2</td>
<td>0.5 (&lt;&lt;) 4.0</td>
</tr>
</tbody>
</table>

- Carbon was immediately redistributed within the soil profile with CT, but not greatly mineralized.
- Surface residue C was lost with CT, but accumulated with NT.
- At the end of 2 years, total C stock (soil + residue) under CT was 5.2 Mg C ha\(^{-1}\) lower and under NT was 3.3 Mg C ha\(^{-1}\) higher than initial C stock (21% difference from initial level of 40.3 Mg ha\(^{-1}\)).

Unpublished data
Pasture-Crop Rotation Study

Soil under NT remained highly stratified with depth
- Low BD at the soil surface
- High BD > 6 cm

Moldboard plowing loosened soil initially following tillage
- However, at 2 years, BD was high >12 cm

Unpublished data
Pasture-Crop Rotation Study

Effect of cover crop management under CT and NT on soil penetration resistance

Soil moisture has big influence on soil penetration resistance.

No major difference in penetration resistance between CT and NT under grazed condition, but lower resistance under CT than NT under ungrazed condition.

Grazing within a tillage system had slight negative effect under CT, but no effect under NT.
Soil moisture had large influence on water infiltration, as expected.

Water infiltration tended to be greater under CT than under NT at low SWC, but lower under CT than under NT at high SWC.

Water infiltration tended to be depressed under cattle grazing of cover crops at SWC >15% under both CT and NT, suggesting that large rainfall events would produce more water runoff when cover crops were grazed than not.

Unpublished data
Summary

✓ Establishment of perennial grass pastures can sequester soil organic C at rates of 0.25 to >1 Mg C ha\(^{-1}\) yr\(^{-1}\)

✓ Soil organic C sequestration rate can be affected by:
  • Forage type (cool- or warm-season) (annual or perennial) (endophyte-infected tall fescue)
  • Fertilization (inorganic or organic source) (rate of application)
  • Forage utilization (grazed or hayed)
  • Animal behavior
Conclusions

- Although some information on SOC sequestration and GHG emission is available, there is a great need to conduct more research on the diversity of pasture systems relevant to agriculture in the eastern USA.

- Well-coordinated studies across climatic gradients and soil conditions are urgently needed to better understand the effects of major management variables, such as forage type, fertilization, and grazing pressure on ecological and economic responses.
Conclusions

✓ Conservation agricultural systems can preserve soil organic C and help mitigate greenhouse gas emission
  ▪ Conservation-tillage cropland
  ▪ Pasture management
  ▪ Pasture-crop rotation

✓ Agricultural contribution to net global warming potential requires more extensive research on N₂O emission and CH₄ flux in the southeastern USA

✓ Low fossil-fuel derived agricultural systems should be developed to further mitigate greenhouse gas emission