Managing Agricultural Landscapes for Ecosystem Services, Productivity & Profit

A Forever Green Agriculture Initiative

Donald Wyse, U of MN
How did agricultural landscapes lose their diversity?
Figure 19. Cover map of the Winnebago pheasant study area, 1941.
Figure 23. Cover map of the Winnebago pheasant study area, 1976.
Protein efficiency 6%
1lb beef 5,214 gal water
1lb potatoes 24 gal water
Protein efficiency 14%
1lb Pork  1,630 gal
water
1lb Potatoes  24 gal
water
What are some of the consequences resulting from the loss of landscape diversity and continuous living soil covers?
Ecosystem Services

The benefits people obtain from ecosystems

- Supporting
  - Nutrient cycling, soil formation...

- Provisioning
  - Food, fuel...

- Regulating
  - Pollination, pest suppression...

- Cultural
  - Recreation, aesthetic...

Costanza et al. Nature 1997
Millennium Ecosystem Assessment 2005
Swinton et al. Am. J of Agric. Econ. 2006
Conceptual framework for comparing land use and trade-offs of ecosystem services

“It sort of makes you stop and think, doesn’t it.”
Minnesota’s Brown Period
Satellite images of vegetative activity.

April 20 – May 3
Areas of perennial vegetation

May 4 – 17
Areas of annual row cropping
Satellite images of vegetative activity.
Satellite images of vegetative activity.

July 13 - 26

October 5 - 18
Annual Tile Drainage Loss in Corn-Soybean Rotation

Waseca, 1987-2001

- July-March: 29%
- April, May, June: 71%
Annual tile flow (inches) (Randall et al., 1997)
Hypoxia in the Gulf of Mexico

bottom dissolved oxygen less than 2.0 mg/L, July 1999

Rabalais et al. 2000
"It sort of makes you stop and think, doesn’t it."
Covering the Brown: Continuous Living Cover
Minnesota Agriculture is Productive

Our Agriculture could achieve more production, efficiency & conservation

**How:** Add winter-annual crops & perennials to summer-annual cropping systems like corn and soybean

**Why:**
- New economic opportunities for farmers & rural communities
- Many other benefits for Minnesota

Visualization of perennial & annual crops in Central Iowa

Larsen, Atwell and Schulte 2010
Adding perennials & winter annuals does four very important things

• Creates value from underused and new resources
• Enhances soil, water, wildlife & biodiversity
• Insures against climate variability
• New economic opportunity
Applying this vision to Midwest Agriculture

**Current Ag Outputs**
- Food
- Feed
- Biofuel (just a little...)

**More Perennials and Winter annuals**
- **More** food & feed
- **Much** more biofuel & natural prod.
- **More** soil, water, wildlife
Getting There from Here: Forever Green

Getting perennials & winter annuals on the landscape by germplasm development, new agronomic practices, commercialization & supply-chain development

- New genetic technologies allow rapid germplasm development
- Develop new agronomic practices (e.g. seeding tech.
- Commercialization: new market opportunities
- Supply chains: from production to end use
Forever Green Plant Based Enterprise Development Projects:

1. Field Pennycress
2. Intermediate Wheatgrass
3. Camelina
4. Winter Barley
5. Hairy Vetch
6. Winter Rye
7. Kura Clover
8. Perennial Sunflower
9. Hazelnut
10. Native Plant Poly-cultures
11. Native Plant Natural Products
12. Perennial Flax
13. Agroforestry
1. Field Pennycress Enterprises:

   Oil—biodiesel
   Protein—food and feed
   Double or relay crop with soybean

   PI D. Wyse
Thlaspi arvense
Pennycress
Brassicaceae
(mustard family)
Extremely cold tolerant winter annual
Rapid seed maturity
High oil content
Double or relay cropping potential with soybean
Diploid/good breeding potential
Pennycress oil for biofuel

- High seed yields – up to 1600 lbs +/- acre in MN

- Seeds high in oil
  - 20-36%/wt = 404 L/acre oil = 87 gal/acre biodiesel

- Ideal composition for biodiesel production
  - 32% erucic (22:1)
  - 22% linoleic (18:2)
  - 11% linolenic (18:3)

- Technology for conversion to biodiesel in place
Fall soybean with pennycress regrowth

Soybean planted no till into pennycress stubble 1st week of June

Pennycress seeded into corn

Pennycress late fall

Corn/PC/Soybean Rotation

Pennycress mid-May
Pennycress with no cover
Late Fall
Oat fall cover
Groundhog radish for fall cover
Late Fall
Pennycress Planting Rates (kg ha\(^{-1}\))

Total oilseed yields at Rosemount, MN in 2012 as affected by planting rate of pennycress and fall cover. Columns with the same letters are not significantly different (LSD =670). Planting rate for oat was 66 kg ha\(^{-1}\) and 11 kg ha\(^{-1}\) for radish.
Weeds/no pennycress vs Weeds/pennycress
Pennycress planting rate (kg ha\(^{-1}\))

Weed biomass at Rosemount, MN in 2012 as affected by planting rate of pennycress. Columns with the same letters are not significantly different (\(\alpha =.05\)).
Pennycress interseeded in corn

Aug 11th  Oct 24th  Nov 10th
Pennycress interseeded in soybean
Pennycress in fall (Oct 24th)
Using *Arabidopsis* and new genomic technologies to improve pennycress

- Identify pennycress genes for important agronomic traits through DNA sequencing
- Develop genomic resources for genomic-assisted breeding
Translation of Arabidopsis-based knowledge to pennycress

- **Spring**: Plant main crop
- **Summer**: Harvest main crop
- **Fall**: Plant winter cover crop
- **Winter**: Harvest winter cover crop

**OG1/GRT2**
- Oil content

**Improved seed characteristics**

**Flowering time pathway**
- Faster flowering

**DOG1**
- GA / ABA Pathways
- Low seed dormancy
Breeding

- Germplasm collected from Europe, South America, and North America
- Total of 72 accessions
- 82 successful crosses made--2013
- High yielding MN lines treated with EMS, Fast Neutron, and Gamma irradiation
- Observation fields planted to observe spring or winter habit, yield, height, oil content, etc.
2. Intermediate Wheatgrass Enterprises:
Beer/Whiskey
Food
Feed
Biomass
Grazing

PI D. Wyse
Intermediate wheatgrass in Minnesota

St. Paul Campus
Intermediate wheatgrass

---- Environment services

- Reduce erosion and soil nitrate leaching
- Reduce inputs of energy and pesticide
- Increase carbon sequestration
Intermediate wheatgrass in Spring

St. Paul Campus
Intermediate wheatgrass

---- Agronomic traits

**Large seeds**

---- 10-15g/1000 seeds

**Large biomass**

---- comparably to big bluestem and switchgrass)

**Disease resistance**

---- Lr38, Sr43, Sr44, Pm40, Pm43...

**Favorable end-use food**

---- wheat-wheatgrass blends
Intermediate wheatgrass

Our goal

— Obtain a commercially viable perennial grain/biomass crop

Wild Perennial

Domestication

Perennial Grain

Increase grain yield and biomass

Enhance grain quality for food
Intermediate wheatgrass Breeding

1st year
2011-2012

2nd year
2012-2013

3rd year
2013-2014

Cross in green house

Spaced plants (2000)

Yield plots (200)

The best plants (50)

Select plants with big seeds, large grain yield and biomass.
Breeding nurseries in St. Paul

2000 spaced plants

440 yield plots
Intermediate Wheatgrass improvement

Seed weight (mg)

- Large seeds

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Wheatgrass Current</th>
<th>Wheatgrass Forage</th>
</tr>
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<tr>
<td>Wheat</td>
<td>35.1</td>
<td>15.0</td>
<td>4.8</td>
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<tr>
<td>Current</td>
<td></td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>Forage</td>
<td></td>
<td>13.8</td>
<td></td>
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1cm
Intermediate Wheatgrass improvement

Non-shattering
## Intermediate wheatgrass improvement

### Second Year Yield of Clone Plots

<table>
<thead>
<tr>
<th>Population</th>
<th>Biomass</th>
<th>Seed Yield</th>
<th>Seed Weight</th>
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<tbody>
<tr>
<td></td>
<td>Minnesota</td>
<td>Kansas</td>
<td>Minnesota</td>
</tr>
<tr>
<td></td>
<td><strong>g m⁻²</strong></td>
<td><strong>mg seed⁻¹</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cycle 0</strong></td>
<td>1690 ±160</td>
<td>1650 ±160</td>
<td>84 ±14</td>
</tr>
<tr>
<td><strong>Clarke</strong></td>
<td>2000 ±160</td>
<td>2170 ±160</td>
<td>117 ±14</td>
</tr>
<tr>
<td><strong>High Seed</strong></td>
<td>2380 ±220</td>
<td>1660 ±110</td>
<td><strong>212 ±19</strong></td>
</tr>
<tr>
<td><strong>Mass line</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>High Seed</strong></td>
<td>1830 ±140</td>
<td>1810 ±100</td>
<td><strong>192 ±12</strong></td>
</tr>
</tbody>
</table>
Best intermediate wheatgrass seed yield in MN 1,882 lb/A

Average spring wheat seed yield in MN 2,820 lb/A
Evaluation of intermediate wheatgrass grain for food use
Starch functionality

Less starch – less viscosity
Protein

Wheat gluten:
- Holds gas
- Viscoelastic properties

Intermediate wheat grass has virtually no gluten forming ability

Developed wheat flour dough:
- IWG hydrates in the Farinograph and does not develop well
- 35.8% water absorption (14% M equivalent, constant dough wt)

Protein patterns of wheat glutens by SDS-PAGE. Lane 1: protein marker; 2: whole wheat flour gluten; 3: Bulk intermediate; 4: IWG LI-1; 5: IWG LI-2; 6: IWG LI-3; 7: IWG LI-4; 8: IWG LI-5A; 9: IWG LI-5B
Dietary Fiber

Insoluble Fiber: 13.4%
Neutral Monosaccharide composition

Soluble Fiber: 3.0%
Neutral Monosaccharide composition

- Glucose: 22% (IWG)
- Arabinose: 22% (Wheat)
- Galactose: 36% (Wheat)
- Xylose: 8% (Wheat)
- Mannose: 3% (Wheat)
Flavor Development in IWG

<table>
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<tr>
<th>Aroma Compound</th>
<th>IWG Concentration (ug/kg)</th>
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<tbody>
<tr>
<td>2-acetyl-1-pyrroline</td>
<td>5.4</td>
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<tr>
<td>2-ethyl-3,5-dimethylpyrazine</td>
<td>0.17</td>
</tr>
<tr>
<td>methional</td>
<td>547</td>
</tr>
<tr>
<td>acetyl formoin</td>
<td>1241</td>
</tr>
<tr>
<td>e-2-nonenal</td>
<td>0.82</td>
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<tr>
<td>2-acetyl-2-thiazoline</td>
<td>37</td>
</tr>
<tr>
<td>e,e-2,4-decadienal</td>
<td>0.69</td>
</tr>
<tr>
<td>2-phenylethanol</td>
<td>32</td>
</tr>
<tr>
<td>furaneol</td>
<td>2296</td>
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</tbody>
</table>
Food products

Cookies are good
Food products

Muffins are OK
Food products

Yeast bread is not good alone
However,

20 to 50% IWG produces a good bread product
Intermediate Wheatgrass Program

• Analyze the Genetic mechanisms of agronomic traits

• Evaluate improved germplasm
  – Evaluate functionality of grain starch and protein
  – Determine seed composition
  – Consumer test grain based products
  – Characterize the flavor

• Develop commercial cultivars
3. Camelina

PI R. Gesch
Camelina

- *Camelina sativa* L. – Brassicaceae (mustard family)
  - AKA false flax
  - High seed oil content ~35-42%
  - ≥ 35% 18:3 α-linolenic
    - Also high in tocopherols
    - **Food and industrial uses**
  - Short life cycle
  - Winter and spring types
  - Double and relay cropping potential
Camelina as a Biofuel Crop

- Advanced biofuel feedstock – aviation fuel
- Diversify cropping systems
  - Disrupt pest and pathogen cycles
  - Suppress weeds
    - Glucosinolates may act to biofumigate soil (Kirkegaard & Sarwar, 1998 P&S)
- Ecosystem services
  - Provide habitat for bees and other beneficial insects
- Requires low agricultural inputs
Excellent Winter Survival

98 ± 13% winter survival – planted mid-September

• Seed yields
  – Winter types generally 1200 – 1500 lbs/acre in MN
  – Spring types as high as 2400 lbs/acre

• Breeding needed to improve yields of winter types
Winter camelina suppresses weeds

Figure 3. Emergence of summer annual weeds, primarily nightshades and pigweeds, was suppressed appreciably by both winter camelina and winter canola compared to that in adjacent summer crops (corn and soybean) in western Minnesota. (USDA-ARS Swan Lake Research Farm, 2013.)
Double-Cropping Advantages

• Provide a winter “cash” cover crop
  – Prevent erosion & take up excess N & P

• Reduce food vs. fuel debate
  – Reduce land-use competition
  – Produce a food and fuel crop in one season

• Added income & potentially more energy
Soybean planted Apr 19
Began emerging May 12

Camelina harvest June 28

Relay-cropping

Soybean
Camelina

Ht (cm)
W. Cam.  78 ± 4
Relay-Soy  27 ± 2
Mono-Soy  36 ± 4
Winter camelina – soybean double crop study (2-yr Avgs.)

Camelina consistently yielded ~1200 lbs/a in all treatments.
Camelina – soybean double crop

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Camelina (L ha⁻¹)</th>
<th>Soybean (L ha⁻¹)</th>
<th>Combined (L ha⁻¹)</th>
<th>Gal/a</th>
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</thead>
<tbody>
<tr>
<td>Double-crop</td>
<td>495</td>
<td>396 c</td>
<td>906 b</td>
<td>97</td>
</tr>
<tr>
<td>Relay-crop-NR</td>
<td>588</td>
<td>513 bc</td>
<td>1101 ab</td>
<td>118</td>
</tr>
<tr>
<td>Relay-crop-YR</td>
<td>615</td>
<td>618 b</td>
<td>1233 a</td>
<td>132</td>
</tr>
<tr>
<td>Swath-DC</td>
<td>564</td>
<td>434 bc</td>
<td>999 b</td>
<td>107</td>
</tr>
<tr>
<td>Mono-Soy</td>
<td>-</td>
<td>915 a</td>
<td>915 b</td>
<td>98</td>
</tr>
</tbody>
</table>

YR = treated with glyphosate; NR = no glyphosate
Swath-DC = swathing camelina before planting soybean
Early fall with winter camelina inter-seeded in soybean (camelina will over winter and flower in spring)
Camelina – Soybean DC System

• Low inputs
  – Can be no-till seeded
  – Low N requirement (40 – 70 lbs/acre)
• Relatively low seasonal water use

![Graph showing water use (mm) between April and September for different cropping treatments. The graph compares 2010 and 2011 data. The treatments include DC-Soy, Swath-DC-Soy, Relay-Soy-NR, Relay-Soy-YR, and Mono-Soy. The treatments are marked with letters a and b to indicate statistical significance.]
Breeding Needs

• Earlier flowering and seed set

• Larger seed size

• Higher oil content and modify fatty acid profile for biofuels and bioproducts

• Improved seed yield of winter types
3. Winter Barley

Enterprises:
Barley malt
Livestock feed
Double crop with soybean

PI K. Smith
Developing Winter Barley for Minnesota
US Malting Infrastructure

Challenges
Climate Change

Climate moves over time
• Westward movement in dust bowl years
• Northward movement in recent years
• 1980 – 2010 rate is 5 miles/year

Climate Tracker Website
http://www.cbs.umn.edu/climatetracker/

Challenges
Winterhardiness

Challenges
Agronomic Benefits

Increased Yield, Disease Avoidance, Weed Suppression, Water Use Efficiency

Fall Planted

Spring Planted

Opportunities
Ecosystem Services

Carbon Sequestration, Nutrient Cycling, Reduced Erosion, Wildlife Habitat
Producer/Industry Benefits

Crop Diversity, Spread Out Field Activities, **Double Cropping**, Earlier Harvest

Opportunities
RESEARCH ACTIVITIES

• Screening wide collection (over 1400 accessions) for winter hardiness
• Generating genomic prediction models to estimate trait phenotypes with genetic markers
• Implementing rapid cycle breeding to accelerate development of winter varieties
• Coordinating national winter barley trial at 14 locations in U.S.
4. Hairy Vetch Enterprises: Nitrogen fixation

PI C. Sheaffer
Winter Hardy
Hairy Vetch
as Cover Crop
in Minnesota
Hairy Vetch, *Vicia villosa*
Advantages of hairy vetch as a winter annual cover crop

• Covers exposed soil in winter and early spring
• Conducts biological dinitrogen fixation (100 lb/acre)
• Produces nitrogen rich biomass for green manuring or harvest in spring
Biological Nitrogen Fixation

Symbiotic relationship with N2 fixing bacteria, *Rhizobium*
Crop Rotation with Cover Crop

- Soybeans
- Hairy Vetch (fall & spring cover)
- Corn
Goals of the breeding project

• Predictable winter survival
• Earlier maturity in spring
• Increased biological dinitrogen fixation
• Reduce dormancy—reduce weedy characteristics
Preliminary research with hairy vetch

• We evaluated 12 ecotypes of hairy vetch from multiple states for winter survival and spring yield.
• We found that winter survival and biomass yield was often greatest for ecotypes obtained in Minnesota.
• We found that the relative risk (based on variability of results) of growing these ecotypes was least for several Minnesota ecotypes.
Percent survival of ecotypes by year and site

Minnesota ecotypes

% survival

Good Thunder, MN
Wadena, MN
Sauk Centre, MN
Ivanhoe, MN
Trilla, IL
Lapeer, MI
Leslie, MI
Murdock, NE
Middletown, MO
Wauseon, OH
Meadville, PA
Halsey, OR

Lam2005
Lam2006
Ros2005
Ros2006
Lam2008
Our Hairy Vetch Ecotype Evaluation and Variety Development

Step 1: Selection among 30 ecotypes
- Winter Hardiness
- Early Maturity/Early Flowering

Step 2: Variety Development
- Breeding program for selected ecotypes
Research Locations & Planting Dates

- Roseau: Aug 20 - Sept 4
- Becker: Sept 3 - Sept 17
- St. Paul: Sept 3 - Sept 17
Ecotypes Evaluated on Different Planting Date
2 weeks after 2nd planting date
5. Winter Rye Enterprises: Nitrogen capture Grazing PI P. Porter
Morris, May 15, 2002
877 lbs/ac

Lamberton, May 15, 2002
1,724 lbs/ac

Waseca, May 15, 2002
1,063 lbs/ac

St. Paul, May 10, 2002
3,102 lbs/ac
Winter Rye Issues

• Develop seeding technology to establishment winter rye in standing crop to reduce risk of establishment failure and maximize fall growth

• Breed winter rye with early maturity, dwarf structure and high tillering
Rye biomass as predicted by ‘RyeGro’

Rye sowing date:

- 15-Sep
- 1-Oct
- 15-Oct
- 30-Oct

Rye Above Ground Biomass (Mg DM ha⁻¹)

Plant soybean
Kill rye
Limited Variability in Winter rye for flowering date

- High heritability for flowering time

- Large environmental effect

- 6 day difference between earliest lines and check cultivar ‘Rymin’

- Low genetic diversity for flowering date

- Must flower earlier to increase management options
Mutation breeding in winter rye for early flowering

- Selected Half-sib families were exposed to sodium Azide at 2 concentrations

- Point mutations will be induced

- Identify plants that flower earlier

<table>
<thead>
<tr>
<th>Initiated Fall 2013</th>
<th>MR423</th>
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<tr>
<td>S</td>
<td>10mM Azide</td>
</tr>
<tr>
<td>N</td>
<td>Control</td>
</tr>
<tr>
<td></td>
<td>5mM Azide</td>
</tr>
<tr>
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<td>10mM Azide</td>
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<tr>
<td></td>
<td>5mM Azide</td>
</tr>
<tr>
<td></td>
<td>Control</td>
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</table>
Winter Rye Aboveground Biomass

- Waseca '02
- Rosemount '02
- Waseca '03
- Rosemount '03

De Bruin, '04
6. Kura Clover Enterprises: Nitrogen fixation

PI J. Baker
Kura clover
Continuous Living Cover
• Honey Production
• Soil conservation
• Pasture; hay
• Living mulch
Kura Clover can fix 150 lb N/acre
Corn in living mulch
Rosemount, MN
2011

Silage production equivalent to conventional corn, with substantially less N fertilizer
Cautions & Challenges

• Difficulty of establishment (Low seedling vigor)
• Shortage of seed (Low seed yield)
• High water use
• Need for better technology (agronomic knowledge, better tillage tools, improved varieties, etc.)
Breeding for Improved Seed Yield and Seedling Vigor

• Poor seedling vigor resulting in stand establishment problems limits the use of kura clover

• Selection for lower root:shoot ratios may increase dry matter partitioning to the shoot and improve establishment.

• Need to breed lines for high seed yield and seed harvest efficiency
Vegetative Propagation
8. Perennial Sunflower Enterprises:
Food grade oil
Biodiesel

PI R. Stupar
Perennial Sunflower

- Work began in 2001 with collection of wild perennial sunflowers
Objectives

• Further the development of perennial sunflower populations that have multiple uses on the landscape

• Identify the genetic factors that control tuber formation, winter hardiness, and branching
Our Strategy

Annual (*H. annuus*)

2n = 2x = 34

Perennial (*H. tuberosus*)

2n = 6x = 102

Intermate with selection for several cycles

Perennial Hybrid

2n = 4x = 68

Final Product

2n = 4x = 68
Perennial sunflower Breeding Program
Assessment of IM₁F₁ populations

• The largest head was 20% larger than the F₁

• Some plants ranked in the top 10% for all yield traits!

• Selection of most extreme individuals to improve breeding populations
Perennial Sunflower Selections
9. Hazelnut Enterprises:
   Nuts
   Oil
   Biodiesel

PI D. Wyse
Native and Native-European Hybrid Hazelnut: a new crop for the Upper Midwest
North American Hazelnuts

• Two hazel species native to Minnesota
  – *Corylus americana*, American hazel
  – *Corylus cornuta*, beaked hazel
• Traditional staple food of indigenous people
• Common in central Minnesota
The European Hazelnut
(Corylus avellana)

- Domesticated independently in Iran, Turkey, and Italy (Boccacci and Botta, 2009)
- Used by humans for thousands of years
- Commercial Production in Turkey, Mediterranean, and Oregon

(Mehlenbacher 2003)
Hybrid Hazelnuts

European Hazel (*Corylus avellana*)
- Large nut size
- Thin shells
- Not cold-hardy
- Susceptible to Eastern Filbert Blight (EFB)

American Hazel (*Corylus americana*)
- Smaller nut size
- Thick shells
- Cold-hardy
- EFB tolerant

Hybrid Hazel
Delicious, Nutritious Hazelnuts

- Excellent source of nutrition
  - Protein
  - Monounsaturated fats
  - Dietary fiber
  - Vitamins E and B₆
- Raw or toasted
- Confections
- Chocolate-hazelnut spread
Hazelnut Oil

- 50-75% of dry weight
- 81% oleic acid
- Many uses:
  - Salad oil
  - Cooking oil
  - Cosmetic products
  - Biofuel

Photos Credit: Mark Shepard
New Economic Opportunities

• Local Food Movement
• “Olive oil of the Midwest”
• Unique opportunities for smaller American and hybrid hazels

www.midwesthazelnuts.org
Hazelnuts as Part of the Forever Green Initiative

• Do not require annual tillage
• Strips between rows can be planted with grass or clover
  – Pollinator habitat
  – Continuous living cover
• Riparian buffers
• Windbreaks
• Living snow fences
Hazelnut Germplasm Improvement

Identification of superior hybrid hazels
- Identify hybrids from on-farm plantings with best kernel quality, yield, EFB tolerance, and cold-hardiness.
- Evaluation in replicated performance trials.

Domestication of American hazel
- Screen wild populations for superior plants.
- Evaluation in replicated performance trials.

The best of the best will be released to growers as a new cultivar.
A Challenge

Too much variability between seed-propagated hazel plants is agronomically unmanageable.

Example: Nut maturation dates
Solution: Vegetative Propagation to produce genetically identical plants

- Mound Layering
- Micropropagation
- Stem Cuttings
Determining Best Management Practices

1. Best Pre-Plant Soil Preparation and Best Weed Control Methods During Establishment

Within-row tillage?  Woodchips within rows?  Planting into killed sod + woodchips?  Landscape fabric?

Comparison Trial to Determine Best Economic Return (Herbicides and treatment intensity are also being evaluated)
Determining Best Management Practices

2. Nitrogen Fertilization for Sustained Nut Bearing

Previous research found that young hybrid hazelnuts need only very low levels of N fertilization, but N requirements are likely to increase when they become productive.
Determining Best Management Practices


**Pruning**
- April, before
- April, after
- May
- Oct

**Coppicing**
- April, before
- April, after
- May
- Oct
10. Native Plant Polycultures

Enterprises:
Biomass
Natural products

PI C. Sheaffer/D. Wyse
Polyculture grasslands for bioenergy

A Forevergreen initiative
Research Questions

• What are the bioenergy yields of various polyculture mixtures (with and without N fertilizer)?

• Can we identify mixtures that are more “stable” than others? Are some less sensitive to drought years?

• What mixtures perform best across various growing conditions?
Research Design

• Species composition: Testing 12 species mixtures
  1. Switchgrass monoculture: 1 species
  2. Big bluestem monoculture: 1 species
  3. Indiangrass monoculture: 1 species
  4. Canada wild rye monoculture: 1 species
  5. Grass polyculture: 4 species
  6. Forb polyculture: 4 species
  7. Legume polyculture: 4 species
  8. Grass and forb polyculture: 8 species
  9. Grass and legume polyculture: 8 species
 10. Forb and legume polyculture: 8 species
 11. Grass, forb, and legume polyculture: 12 species
 12. High diversity: 24 species
Research Design

**Primary**
- Switchgrass
- Big bluestem
- Indiangrass
- Virginia wild rye

**Native Grasses**

**Primary**
- Maximilian sunflower
- Yellow coneflower
- Stiff goldenrod
- Purple coneflower

**Secondary**
- Sideoats grama
- Little bluestem
- Slender wheatgrass
- Canada wild rye

**Native Legumes**

**Primary**
- Showy tick trefoil
- Purple prairie clover
- Lead plant
- Canada milkvetch

**Secondary**
- American licorice
- Pale pea
- White prairie clover
- American vetch

**Native Non-legume Forbs**

**Primary**
- Northern bedstraw
- Wild bergamot
- Black-eyed Susan
- Golden Alexander

**Secondary**
-...
Legumes in polycultures
Grass Polycultures
Research Design

• Split plot design: Two fertilizer treatments as main plots
  - 60 lbs. per acres N fertilizer
  - 0 N; control

• 12 species mixtures

• Three replicates per location

• 9 locations
• 9 Research Locations
• Split Plot design
  - Fertilization
• Monitor research experiments for 10 yrs.
  - Biomass Yield
  - Botanical Composition
  - Nutrient Export
Preliminary Results

Variation in biomass yields by species, nitrogen and location treatment
## Preliminary Results

Highest yielding species treatments averaged across all years at each location. No N fertilizer.

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum yielding treatment</th>
<th>Yield T/A SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Paul</td>
<td>Grass polyculture</td>
<td>2.4 (1.2)</td>
</tr>
<tr>
<td>Waseca</td>
<td>Switchgrass monoculture</td>
<td>2.8 (0.7)</td>
</tr>
<tr>
<td>Lamberton</td>
<td>Grass polyculture</td>
<td>3.9 (0.6)</td>
</tr>
<tr>
<td>Becker</td>
<td>Switchgrass monoculture</td>
<td>1.5 (0.4)</td>
</tr>
<tr>
<td>Roseau</td>
<td>High diversity polyculture</td>
<td>2.8 (1.2)</td>
</tr>
<tr>
<td>Red Lake Falls</td>
<td>Grass + Legume polyculture</td>
<td>2.9 (1.2)</td>
</tr>
<tr>
<td>Mahnomen</td>
<td>Grass + Legume + Forb Polyculture</td>
<td>2.1 (0.7)</td>
</tr>
<tr>
<td>Crookston</td>
<td>Grass + Legume polyculture</td>
<td>2.7 (1.0)</td>
</tr>
<tr>
<td>Fargo</td>
<td>Grass + Legume polyculture</td>
<td>1.7 (0.8)</td>
</tr>
</tbody>
</table>
### Preliminary Results

Highest yielding species treatments averaged across all years at each location. 60 lb N applied per acre.

<table>
<thead>
<tr>
<th>Location</th>
<th>Maximum yielding treatment</th>
<th>Yield T/A SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Paul</td>
<td>Grass + Forb polyculture</td>
<td>2.9 (1.1)</td>
</tr>
<tr>
<td>Waseca</td>
<td>Switchgrass monoculture</td>
<td>3.9 (1.0)</td>
</tr>
<tr>
<td>Lamberton</td>
<td>Grass polyculture</td>
<td><strong>4.7 (1.0)</strong></td>
</tr>
<tr>
<td>Becker</td>
<td>Grass + Legume polyculture</td>
<td>2.1 (1.0)</td>
</tr>
<tr>
<td>Roseau</td>
<td>Canada Wild Rye monoculture</td>
<td>2.8 (1.1)</td>
</tr>
<tr>
<td>Red Lake Falls</td>
<td>Grass + Legume polyculture</td>
<td>3.3 (1.2)</td>
</tr>
<tr>
<td>Mahnomen</td>
<td>Legume + Forb polyculture</td>
<td>2.7 (0.4)</td>
</tr>
<tr>
<td>Crookston</td>
<td>Grass polyculture</td>
<td>3.8 (1.3)</td>
</tr>
<tr>
<td>Fargo</td>
<td>Big Bluestem monoculture</td>
<td>2.3 (0.4)</td>
</tr>
</tbody>
</table>
AFEX™ Pellets: A Versatile Biomass Commodity

- Biorefinery sugar feedstock
- Releases 75+% of sugars for fuels and chemicals
- Ruminant animal feed for beef and dairy cattle
- Potential to displace corn grain
Supply Chain Scenario

- 18 million gallons/yr Isobutanol
- 900 Tons/day biomass commodity
- Target cellulosic sugars (~$0.15/lb)

Assumption:
- Average annual yield of 3 tons/acre, $80/ton
- Average hauling distance to depot 10 miles
- Biomass feedstock ~10% of land base

Cattle Feed
- Corn @ $6/bu: $236/ton

Figures audited by DOE 2013
11. Native Plant Natural Products

Enterprises:

Antioxidants
Antimicrobials
Aromatics

PI A. Hegeman/D. Wyse
Developing Economically Valuable Natural Products from Native Minnesota Plants

University of Minnesota and Aveda Collaboration

Alison D. Pawlus, Amanda C. Martin, Tim Kapsner, Tiffany Thompson, Annette Popp, Donald L. Wyse, Cindy K. Angerhofer, Adrian D. Hegeman

University of Minnesota, Twin Cities
Departments of Horticultural Science, Plant Biology, Agronomy and Plant Genetics, and the Microbial and Plant Genomics Institute
Botanicals Research Team in Estée Lauder R&D
Project Vision

Activities
1. Identify Natural Preservatives
2. Construct Botanical Library
   • Resource for Future Screening:
     o Anti-inflammatory, 5-LOX, NF-κB, etc.
     o Antioxidant
     o Anti-aging, MMP Inhibition, etc.
     o Hair loss & Graying

Outcomes
1. Natural Based Preservatives
2. Screenable Natural Resource for High Interest Biological Activities
3. Positive ecosystem services
Project Vision

Native MN perennial plants ➔ Preservatives for products ➔ Good for...

- Our environment
- Our local economy
- Our health
Project Workflow

Set up partnership and target specific plants in Minnesota

Test plant organs for antioxidant and antimicrobial activity

Optimize collection and compound identification process

Increase throughput, landscape diversity, and expand markets
Why natural preservatives for the cosmetic and personal care market?

• Environmental concerns
• Health concerns
• Public opinion
• List of acceptable ingredients dwindling
• Organic and natural personal care products 8.8% growth in 2010
• Aveda Leader in Innovation
  o Goal of 100% Petroleum Free Products
  o “Care for the World We Live In”
Plant Material

• Native MN plant
  o “[a plant] that is part of the balance of nature that has developed over hundreds or thousands of years in a particular region or ecosystem”
    - USDA Natural Resources Conservation Service

• Plant material and seed collected from
  o Scientific and Natural Areas (SNAs)
  o The Nature Conservancy natural areas (TNCs)
  o MN State Parks
  o UMN experiment station ecological areas
  o Railway roadside ditches
Plant Material

• >200 different MN plants collected as part of botanical library construction

• Key species placed into a field trial to evaluate performance in a controlled setting
MN Native Plant Collection Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>#</th>
<th>Location</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bronson Lake state Park</td>
<td>1</td>
<td>Compass Prairie SNA</td>
<td>18</td>
</tr>
<tr>
<td>Pembina Trail Reserve SNA</td>
<td>2</td>
<td>Des Moines River prairie SNA</td>
<td>19</td>
</tr>
<tr>
<td>Agassiz Dunes SNA</td>
<td>3</td>
<td>Martin County Roadside</td>
<td>20</td>
</tr>
<tr>
<td>Itasca state Park</td>
<td>4</td>
<td>Faribault County Roadside</td>
<td>21</td>
</tr>
<tr>
<td>Bluestem Prairie SNA and Buffalo River State Park</td>
<td>5</td>
<td>SROC (Waseca)</td>
<td>22</td>
</tr>
<tr>
<td>Western Prairie SNA</td>
<td>6</td>
<td>UMORE (Rosemount)</td>
<td>23</td>
</tr>
<tr>
<td>Ottertail Prairie SNA</td>
<td>7</td>
<td>Brown County Roadside</td>
<td>24</td>
</tr>
<tr>
<td>Inspirational Peak State Park</td>
<td>8</td>
<td>Afton state park</td>
<td>25</td>
</tr>
<tr>
<td>Kerrick Roadside</td>
<td>9</td>
<td>William O'Brian state</td>
<td>26</td>
</tr>
<tr>
<td>Nickerson Roadside</td>
<td>10</td>
<td>Janesville roadside</td>
<td>27</td>
</tr>
<tr>
<td>Glacial Lake State Park</td>
<td>11</td>
<td>Glynn Prairie SNA</td>
<td>28</td>
</tr>
<tr>
<td>Cedar Creek Ecosystem Science Reserve</td>
<td>12</td>
<td>Lundblad Prairie SNA</td>
<td>29</td>
</tr>
<tr>
<td>Kasota prairie SNA</td>
<td>13</td>
<td>Osmundson Prairie SNA</td>
<td>30</td>
</tr>
<tr>
<td>Cottonwood Prairie SNA</td>
<td>14</td>
<td>Lyon county roadside</td>
<td>31</td>
</tr>
<tr>
<td>SWROC (Lamberton)</td>
<td>15</td>
<td>Kanabec County roadside</td>
<td>32</td>
</tr>
<tr>
<td>Redwood County Roadside</td>
<td>16</td>
<td>Pine County roadside</td>
<td>33</td>
</tr>
<tr>
<td>Prairie Coteau SNA</td>
<td>17</td>
<td>Pine county 123</td>
<td>34</td>
</tr>
</tbody>
</table>
Native Plant Common Garden Establishment Summer 2011
Native & Naturalized Plant Collection

Plant Extractions & Partitions

High-Throughput Biological Testing

Informs Plant Collections

Isolation & Structure Elucidation

Chemical profiling

1. Sulfuretin
2. Butein
3. Scopoletin
4. Methyl gallate
5. Ethyl gallate
6. R₁ = Rhamnose, Myricitrin
7. R₂ = Glycoside, Myricetin 3-O-glycoside
Bioassay-guided Fractionation

Active Extract Partition

Silica Gel Flash Chromatography

Fraction 1-3

Fraction 4

Fraction 6-10

Sephadex LH-20

Semipreparative HPLC

Pure Compound

Identified using high resolution mass spectrometry (HRMS), nuclear magnetic resonance (NMR), optical rotation, UV, IR, etc.

Biological Testing
Current Antimicrobial Testing

- **Candida albicans**
  - Fungus
- **Staphylococcus aureus**
  - Gram(+) bacteria
- **Pseudomonas aeruginosa**
  - Gram(-) bacteria
  - Aerobic
- **Escherichia coli**
  - Gram (-) bacteria
  - Facultative anaerobic
- **Aspergillus niger**
  - Filamentous fungus (mold)

Source: www.inhabit.com
Antimicrobial Screening Results

1. Previous Work:
   • > 1000 MN native and naturalized plants pre-screened
   • Disk-diffusion antimicrobial assay

2. 120 Most active from previous work, recollected & screened
   • Using partitions and MIC assay to identify water soluble actives)

3. Evaluated actives: Focused recollection

4. To date: 220 plants screened
   • Representing 76 plant families
   • 99 Species are active against at least 1 microbe
   • 15: Deemed highly promising leads
     o Good biological activity (> 1 microbe)
     o Water soluble active components
     o Promising phytochemistry:
       ▪ Non-toxic/-allergenic/-irritant
       ▪ Additional relevant biological activities
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Benefits to UMN

• Proprietary Technology
• Unique Library of Plant Extracts for Future Screening
• Publications
• Leveraging Technical Expertise from MN based Industries
• High Value Collaborations
• Training Opportunity
  o Post-doctoral Fellows
  o Graduate Students
  o Undergraduate Research Assistants
  o UROP projects
Project Publications

Journal of Medicinal Plants Research

Antimicrobial activity of native and naturalized plants of Minnesota and Wisconsin 2008
Joy R. Borchardt¹, Donald L. Wyse¹, Craig C. Sheaffer¹, Kendra L. Kauppi², R. Gary Fulcher³
Nancy J. Ehlke¹, David D. Biesboer⁴ and Russell F. Bey²

Antioxidant and antimicrobial activity of seed from plants of the Mississippi river basin 2008

Optimization of screening of native and naturalized plants from Minnesota for antimicrobial activity 2012
Peter Gillitzer¹, Amanda Cecilia Martin², Michael Kantar¹, Kendra Kauppi³, Steve Dahlberg⁴,
Dmitry Lis¹, Jim Kurle⁵, Craig Sheaffer¹ and Donald Wyse¹*

Phytochemical Analysis, 2013 (in review)

Optimized plant extractions for phytochemical library construction:
Evaluating solvent systems using metabolomics approaches
Amanda C. Martin¹, Alison D. Pawlus¹, Erin M. Jewett¹, Donald L. Wyse², Cindy K.
Angerhofer³, Adrian D. Hegeman¹

* Same authors as above
12. Perennial Flax Enterprises:
Food grade oil
Biodiesel

PI D. Wyse
Perennial Flax

• Began in 2001 with observation blocks of wild perennial flax from the USDA-GRIN system and Black Hills State University (South Dakota)

• Germplasm included two genomic groups, x=9 (self-incompatible) and x=15 (largely self-pollinated)

• Hybridization began in 2004 within and between these groups
Perennial Flax

• Goals of perennial flax improvement
  – Increase seed size
  – Improve wintering ability
  – Select for ability to produce 2 crops per year

Regrowth of nursery plant
1 month after harvest
13. Agroforestry Enterprises:

Food products
Fuel products

PI C. Sheaffer/D. Current/D. Wyse
Introduction

Agroforestry has been proposed for sustainable biomass cropping

• Potential to utilize “marginal”, depositional, or lowland sites
  • Strategic niches to minimize competition with food crops

• Potential for increased ecosystem services
  • Wildlife / pollinator habitat
  • Carbon sequestration
  • NPS pollution reduction / water quality

• Landscape and feedstock diversity
Introduction

• Limited information on biomass crop potential in agroforestry systems in U.S. Midwest

• Successful crop establishment is critical to stand longevity and maximizing productive potential

• We need to develop systems before farmers can adopt!
Therefore, our short-term objectives were to:

• To evaluate establishment and yields of biomass crops in an alley cropping system.

• To evaluate the effects of tree-crop interactions on productivity and establishment.
Methods: crops

‘Fish Creek’ willow planted in “twin row” system
14,332 trees ha⁻¹

‘NM6’ poplar planted at 1.2 m grid spacing
6,670 trees ha⁻¹

(Salix purpurea x S. purpurea)  (Populus nigra x P. maximowiczii)
Methods: crops

- **Switchgrass**
  (*Panicum virgatum* L.)
  - Local ecotype broadcast at 18.2 kg ha\(^{-1}\) (193 seeds m\(^{-2}\))

- **Prairie Cordgrass**
  (*Spartina pectina* Bosc ex Link)
  - Local ecotype propagated at 107,593 plants ha\(^{-1}\) (10.8 plants m\(^{-2}\))
Methods: crops

- **Native tallgrass polyculture**
  - 4 forbs, 4 legumes, 3 grasses broadcast at 17.1 kg ha$^{-1}$ (384 seeds m$^{-2}$)

- **Alfalfa - intermediate wheatgrass mixture**
  - Alfalfafa (*Medicago sativa* L.) Pioneer ’54V48’ at 5.7 kg ha$^{-1}$
  - ‘Rush’ intermediate wheatgrass (*Thinopyrum intermedium* [Host] Barkworth and Dewey) at 9.1 kg ha$^{-1}$
Methods: design

- RCBD in split plot arrangement
- 3 on-farm sites: Fairmont, Empire, and Granada, MN
  - 2 floodplain, 1 stream terrace
- 3 years (2010 - 2012)
- 2 woody crops, 4 herbaceous crops
- 15.2 m alley
Methods: design

Alley orientation

Empire  Fairmont  Granada
Methods: sampling

Herbaceous crop sampling – evaluating effects of proximity to trees

- Alley center

- Alley edge

- 7.6 m

- 2.5 m
Methods: sampling

Tree sampling – evaluating effects of proximity to edge

- Center rows
- Edge rows

$n_{\text{poplar}} = 8$  
$n_{\text{willow}} = 6$
Results & discussion

Figure 2: Short rotation willow and poplar survival 3, 12, and 30 months after establishment in alley cropping systems at three Minnesota sites
Figure 2: A) Basal area per tree and B) Stand basal area (per hectare) for alley cropped short rotation woody crops following the third growing season in 2012. Means +/- standard errors are presented.
Figure 3: 2012 average basal area per hectare by clone and row position for alley cropped short rotation woody
Table 2: Establishment index and weed density for four herbaceous alley crops at two Minnesota sites 45 days after seeding.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Planting rate (PLSm⁻²)</th>
<th>Establishment index</th>
<th>Weed density (seedlings m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Empire</td>
<td>Granada</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>1,481</td>
<td>0.21 br⁺</td>
<td>0.33 br</td>
</tr>
<tr>
<td>Alfalfa – wheatgrass</td>
<td>439</td>
<td>0.82 ar</td>
<td>0.90 ar</td>
</tr>
<tr>
<td>Native polyculture</td>
<td>770</td>
<td>0.18 cr</td>
<td>0.21 br</td>
</tr>
<tr>
<td>Prairie cordgrass</td>
<td>10.8‡</td>
<td>0.93 r</td>
<td>0.82 s</td>
</tr>
</tbody>
</table>

*Within each column and row, means with the same letter are not significantly different based on Tukey's HSD (0.05). Letters a – c are used to denote differences among treatments, while letters r – s are used to denote differences between sites.

‡Live rhizomes were planted rather than seed, thus comparisons to seeded treatments were not made.

§Emergence index is calculated as average seedling density / planting rate.

NA: Not applicable; this data was not collected.
Results & discussion

Dry matter yield of alley cropped herbaceous biomass over three years following establishment at Granada MN

Means +/- standard errors
Results & discussion

Dry matter yield of alley cropped herbaceous biomass over three years following establishment at Empire, MN

Means +/- standard errors
Summary

• Herbaceous productivity
  • Good herbaceous crop establishment (high indices)
  • Native polyculture & prairie cordgrass were most productive herbaceous crops so far
  • No difference in edge vs. center alley, but yields are declining overall, possible effect of alley orientation

• Woody productivity
  • Excellent tree survival
  • Edge effects due to alley proximity
  • Differences between clones due to:
    • Tree spacing, individual tree size, coppice / no coppice management, site adaptability
Next steps

• Effects of interspecies interactions on resource availability and productivity in the alley cropping system
  • What is causing herbaceous yield decline? (light, water, N availability?)
  • Why no edge effects in herbaceous crops?
• Woody biomass harvest and allometrics
• Root biomass distribution and C accumulation since conversion from annual crops
Alley Cropping Systems: Biological Control Index
Agricultural landscapes are dominated by a few annual crops. More land in corn means less grassland and forest habitat for beneficial insect predators and there are more outbreaks of agricultural pests.
Soybean aphid is a major pest in the upper Midwest
Soybean aphid causes yield decreases of up to 40%

Before 2000: Less than 0.1% of soybean acreage sprayed

Today: Up to 50% of soybean acreage sprayed

Biological control from native insects as an alternative to insecticide spraying

C. Lewis (UMN Extension)
Insect Predators of Soybean Aphids in the Upper Midwest

Photo Credit: P. Bryant, M. Rice, T. Murray, J. Eckberg
Integrate perennial crops into soybeans to attract predators of the soybean aphid.

Tilman et al 2006, Peng et al 1993
Integrated perennial cropping systems support biological control of the soybean aphid and produce perennial bioenergy.

Photo Credit: University of Wisconsin