Ecological Sustainability of Alternative Biomass Feedstock Production for Bioenergy & Environmental Benefits

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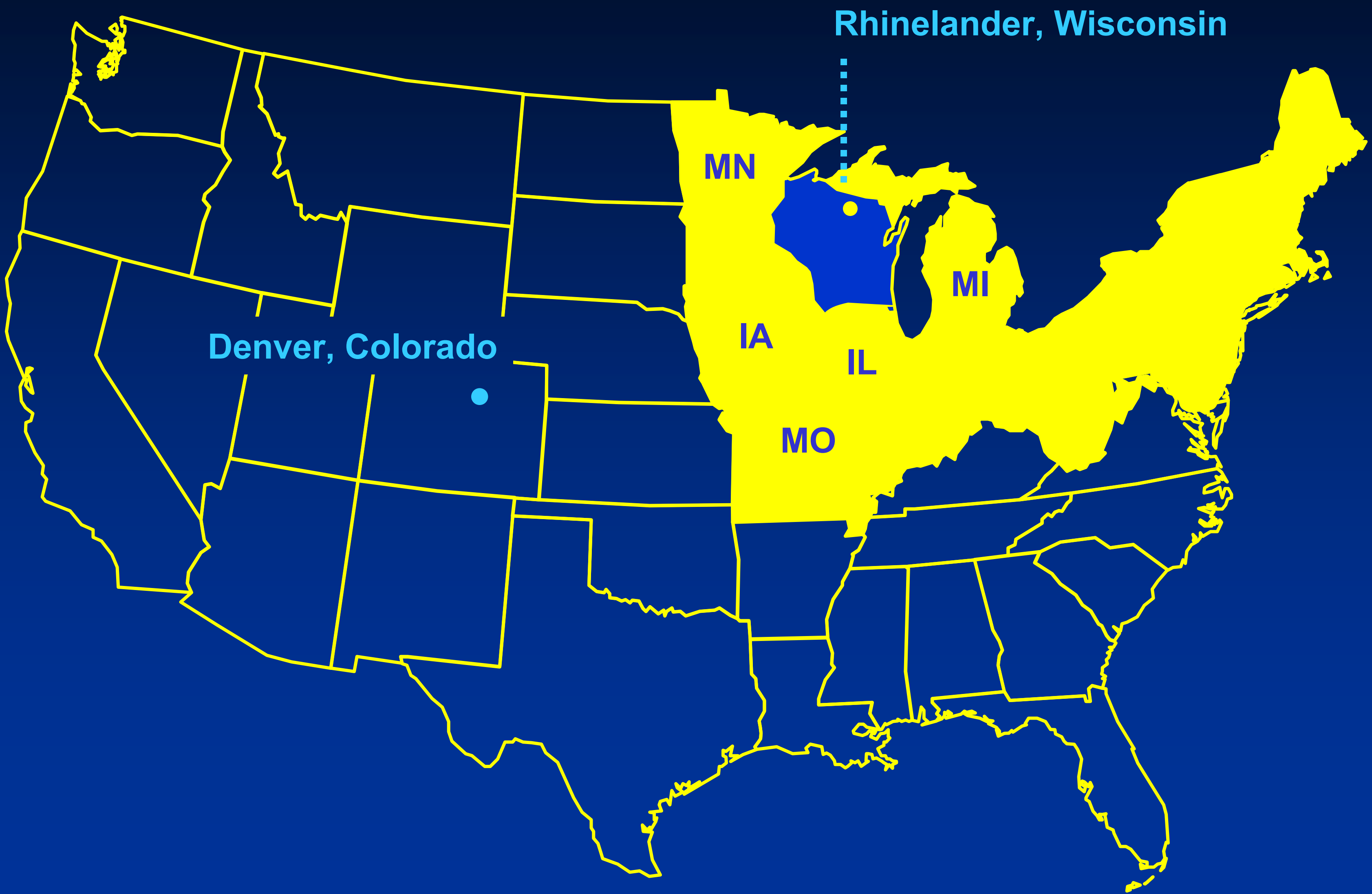
R.S. Zalesny Jr. presented the results of this study during Session 5A (BioFuels) of the Fourth International Phytotechnology Conference; September 24-26, 2007; Denver, CO.

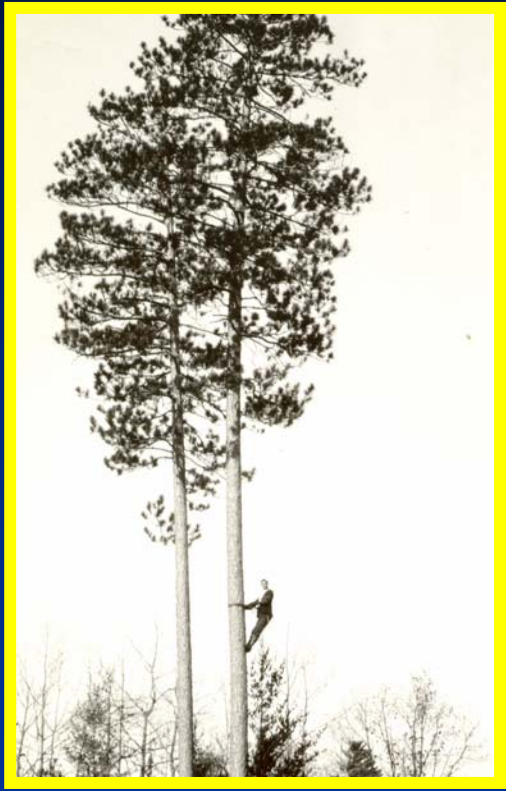
Northern Research Station



Lake States Genetics Research

- Forest Service studies began in 1927
- All major conifer species
  - Range-wide & regional collections
  - Common garden tests
  - Community approach (states, universities)
- Short rotation crops began ~1970,

  with emphasis on limits to productivity
  - Focus on species & varieties
  - Focus on agricultural-type inputs
  - Advantage of hybrid poplars proven



Poplar Genetics Research

- **Northeastern - 1920's**

  1924 to 1939: 13,000 hybrids

- **North Central (IL) - 1950's**
- **North Central (MN) - 1960's**
- **Pacific Northwest - 1960's**
- **USFS Lake States**

  1937 - 1940: 25 Oxford Paper Company clones planted in lower Michigan

  1950: LSFES rejected Schreiner's idea for collaborative study

  1983: Poplar genetics research began

March 1, 1939

TESTS ON OXFORD HYBRID POPLARS

By W. A. Kluender, Assistant to Technician, Lake States Forest Experiment Station1/

GENERAL

Since 1924 the Oxford Paper Company of Frye, Maine, has developed over 13,000 new poplar hybrids. Recently, the Northeastern Forest Experiment Station took over these studies and has arranged to test the more promising hybrids in several typical sections of the country. One such test was established in 1938 at the Chittenden Nursery in lower Michigan in cooperation with the Lake States Forest Experiment Station and Region 9. For this purpose the region made available its nursery facilities and the experiment station supervised the planting of the cuttings and maintained necessary records of survival, growth, and development.

1/ The work was conducted under the supervision of Paul O. Rudolf, Associate Silviculturist, Lake States Forest Experiment Station. Acknowledgment is made of the splendid cooperation received from the Chittenden Nursery personnel.

North Central Poplar Breeding

~40,000
+
~48,000

~88,000 Genotypes

+ Previous

>100,000 Genotypes

North Central Poplar Breeding

(R. Hall – ISU)

- **Mostly F_1 hybrids** (DD, DM, MD)
- **Currently, about 34 clones being scaled up for use**
- **135% yield increase over existing clones**

North Central Poplar Breeding

(B. MacMahon – UMN NRRI)

- Mostly F_1 hybrids (DD, DN, DT, DM)
- Some advanced generation hybrids (BC_1) [(TD) × D]
- Currently, about 150 clones being scaled up for field testing
- Yearly breeding:
  - 80 to 100 crosses
  - 60 to 100 seedlings per family
  - After mortality, etc., 3500 to 6000 seedlings
- Nursery testing
  - 30 families × 30 individuals = 900 genotypes every two years
- Four years of field testing

Advanced Generation Hybrids

♀ *P. trichocarpa* (Washington) × ♂ *P. deltoides* (Minnesota)

↓

♀ F_1 Hybrid × ♂ *P. deltoides* (Minnesota)

↓

First Generation Backcross (BC_1)

- 4 × 3 factorial mating design
- 10 of 12 families
- 576 seedlings at Rhinelander, WI
- 576 seedlings at Grand Rapids, MN

What is a Hybrid Poplar?

- Hybrid poplars are members of the willow family (Salicaceae) & the genus *Populus*
- 6 sections within *Populus*
    1) *Abaso* (Mexican poplar)
    2) *Leucoides* (swamp poplars)
    3) *Turanga* (Afro-asian poplars)
    4) *Populus* (aspens & white poplars)
    5) *Tacamahaca* (balsam poplars)
    6) *Aigeiros* (cottonwoods & black poplar)

Crossability

The Genus *Populus*

- ~ 30 species worldwide
- Broad genetic variation at species level
- Small genome (corn 6× larger, loblolly pine 40× larger)
- Diploid, 2n = 38; Triploid, 3n = 57 (human 2n = 46; corn 2n = 20)
- Deciduous, leaves alternate & simple
- Dioecious, male or female trees (~ 1:1 ratio)
- Vegetative propagation

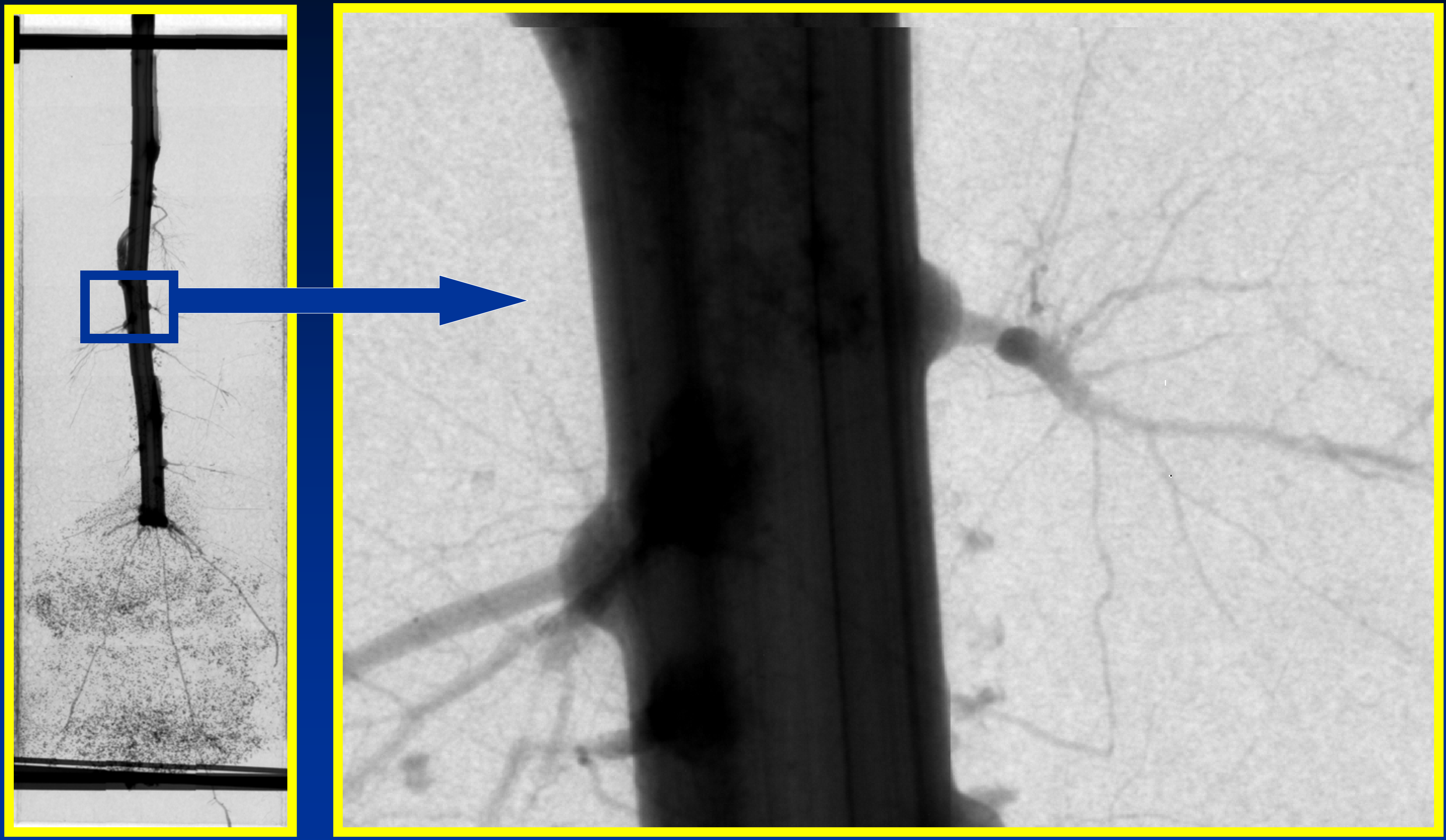
September 15, 2006

Crop Development Strategy

Fiber & Bioenergy

	Rooting	Pest & Disease	Yield
P. deltoides	E	G	G
P. trichocarpa	VG	VB	G
P. nigra	G	B	G
P. maximowiczii	VG	B	G
Hybrids	G	E	VG
Adv. Generation	G?	G?	G?

Rooting



Rooting

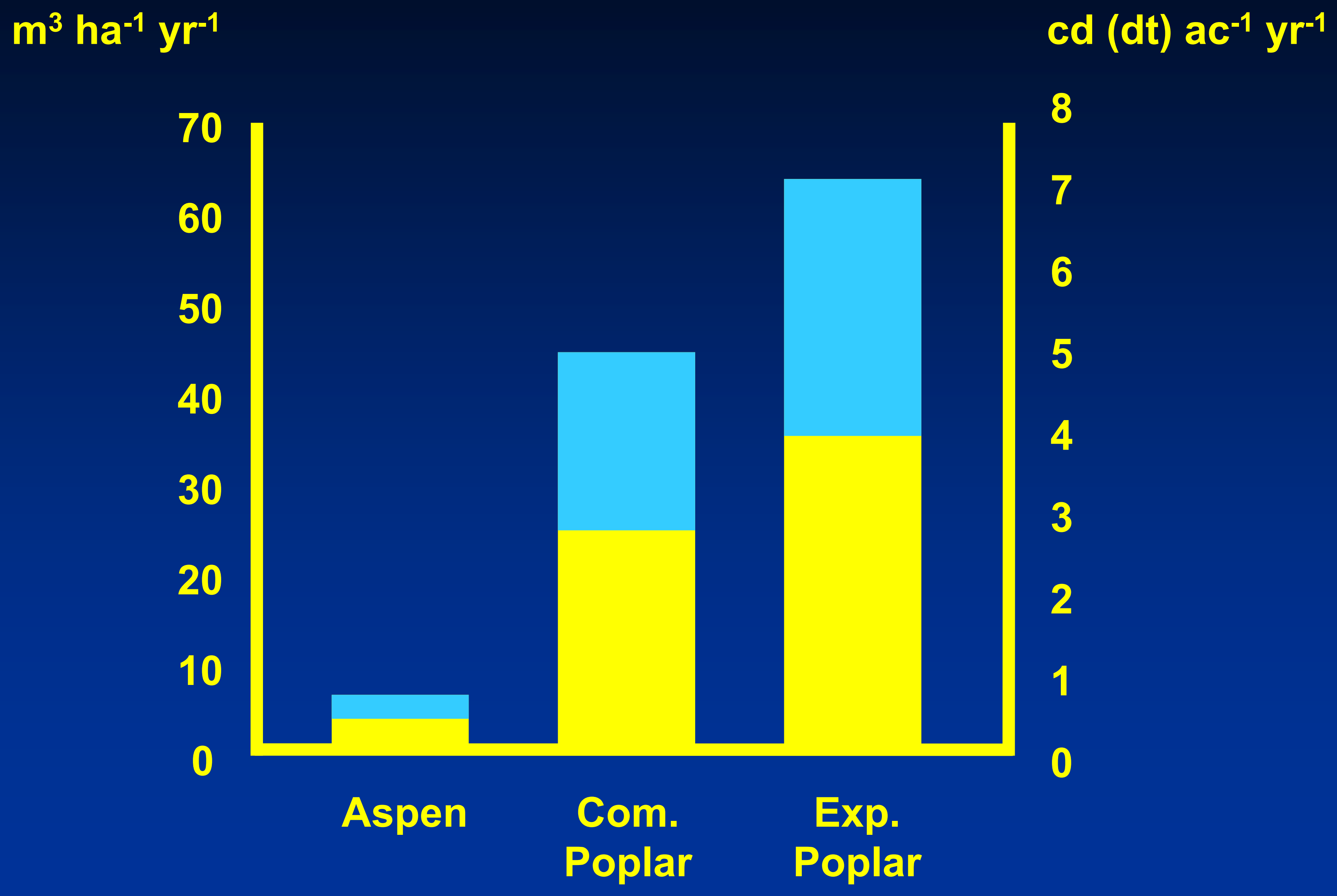
Pests & Diseases

Cottonwood Leaf Beetle

Septoria Canker

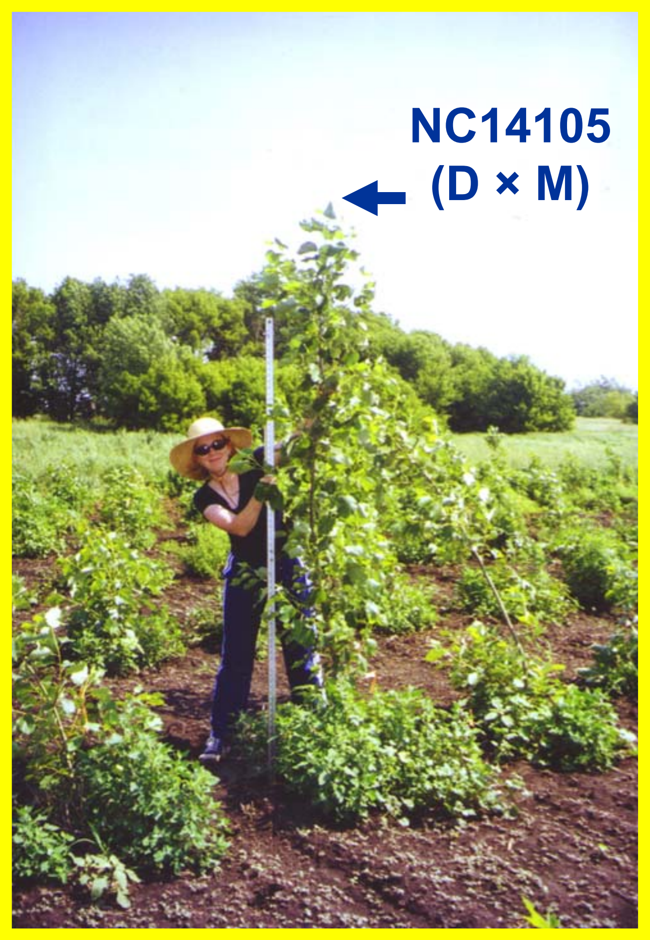
Leaf Rust

Yield


m3 ha-1 yr-1
cd (dt) ac-1 yr-1
70
60
50
40
30
20
10
0
8
7
6
5
4
3
2
1
0
Aspen
Com. Poplar
Exp. Poplar

Yield

D133
(D)



Bioenergy

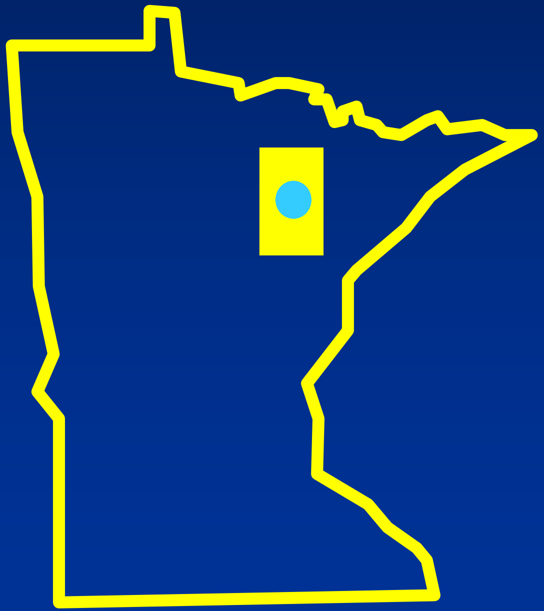
- Biomass for Electricity
- Ethanol
- Pellets
- Cordwood

Bioenergy

Biomass for Electricity

- Laurentian Energy Authority
  - Public Utilities Commissions of Hibbing & Virginia, MN

St. Louis County Population: ~200,000



Bioenergy
Biomass for Electricity

- Laurentian Energy Authority
  - 1994 State Legislature passed legislation that Xcel Energy produce 110 MW of renewable generation, 35 MW needs to be closed loop (grown specifically for power generation)
  - Power purchasing agreement from Xcel Energy ($80 million)
  - 35 MW of renewable green power (40,000 acres of poplar)
    - 20 MW Hibbing, 15 MW Virginia
  - $1.2 billion economic impact ($700 million in gross revenues) over 20 years
  - Retention of 70 jobs, creation of >100 jobs
  - Biomass plants went operational during the winter of 2007

Bioenergy

Ethanol: Why Use Cellulose for Energy?

- Energy Policy Act of 2005 mandates a 7.5 billion gallon ethanol production by 2012 (increase of ~ 3.5 to 4.0 billion gallons)
- Can U.S. corn production sustain this level?
  - 2.8 gallons per bushel of corn
  - 4 billion gallons consumes 1.4 billion bushels
  - At 39.4 bushels per metric ton, we need 36.3 million metric tons
  - In FY2006, U.S. exported 56 million metric tons*
  - Thus, ethanol would consume 65% of corn exported
  - Does this cause a "fuel versus food" issue?

* Source: U.S. Grains Council (http://www.grains.org)

Bioenergy

Ethanol: Alternative Energy Crops

- Demonstrated yields up to 5 dt ac^{-1} yr^{-1} (45 m^3 ha^{-1} yr^{-1})
- 350 gallons of ethanol ac^{-1} yr^{-1} (assuming 70 gal dt^{-1})
- 11.4 million acres can produce 4 billion gallons of ethanol per year
  - 17% of the size of Colorado (66.6 million acres)
  - 108% of the size of Denmark (10.6 million acres)
- Advantages
  - Carbon accountable, environmental advantages
  - Better input / output energy balance possible
  - Crop alternatives link agencies – grasses & trees
  - Crop alternatives link landscapes – forest & agriculture

Bioenergy

Energy Crops are Becoming a Free-Market Possibility

	Cost $MBtu^{-1}$	Cost $Unit^{-1}$	Energy $Unit^{-1}$
Electricity	$36.67	$0.11 kwh^{-1}	0.003 MBtu kwh^{-1}
Gasoline	$23.76	$2.97 gal^{-1}	0.125 MBtu gal^{-1}
Petro-Diesel	$22.21	$2.91 gal^{-1}	0.131 MBtu gal^{-1}
LP Gas / Propane	$18.95	$1.80 gal^{-1}	0.095 MBtu gal^{-1}
Fuel Oil #2	$16.57	$2.32 gal^{-1}	0.140 MBtu gal^{-1}
Pellets	$12.20	$170.00 dt^{-1}	13.9 MBtu dt^{-1}
Natural Gas	$8.34	$0.834 $therm^{-1}$	0.1 MBtu $therm^{-1}$
Energy Crops	$4.24	$73.00 dt^{-1}	17.2 MBtu dt^{-1}
Coal	$1.21	$31.50 ton^{-1}	26 MBtu ton^{-1}

Information Sources (9/6/2007):

- U.S. Energy Information Administration (http://www.eia.doe.gov)
- Wisconsin Public Service (http://www.wisconsinpublicservice.com)
- Pellet Fuels Institute (http://www.pelletheat.org)
- U.S. Forest Service, Forest Products Laboratory (http://www.fpl.fs.fed.us)

MBtu = million Btu

British Thermal Unit (Btu) = amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit

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Environmental Benefits

- **Incorporating intensive forestry with waste management for the application of phytotechnologies**

Utilizing sustainable recycling of waste waters as irrigation & fertilization for alternative biomass feedstock production systems

Environmental Benefits

- A common protocol has been to utilize a limited number of readily-available genotypes with decades of deployment in other applications (e.g. fiber, windbreaks)
- It is possible to increase the success of phytotechnologies with proper genotypic screening & selection, followed by field establishment of favorable clones

Crop Development Strategy

Phytotechnologies

	Rooting	Pest & Disease	Yield	Other
P. deltoides	E	G	G	?
P. trichocarpa	VG	VB	G	?
P. nigra	G	B	G	?
P. maximowiczii	VG	B	G	?
Hybrids	G	E	VG	?
Adv. Generation	G?	G?	G?	?

Limits to Clone Transfer

Clone Stability and G × E Interaction

If variation due to the clone main effect is strong, then clone performance is stable.

- Generalist genotypes that perform well over a broad range of contaminants (most readily-available genotypes are generalists).

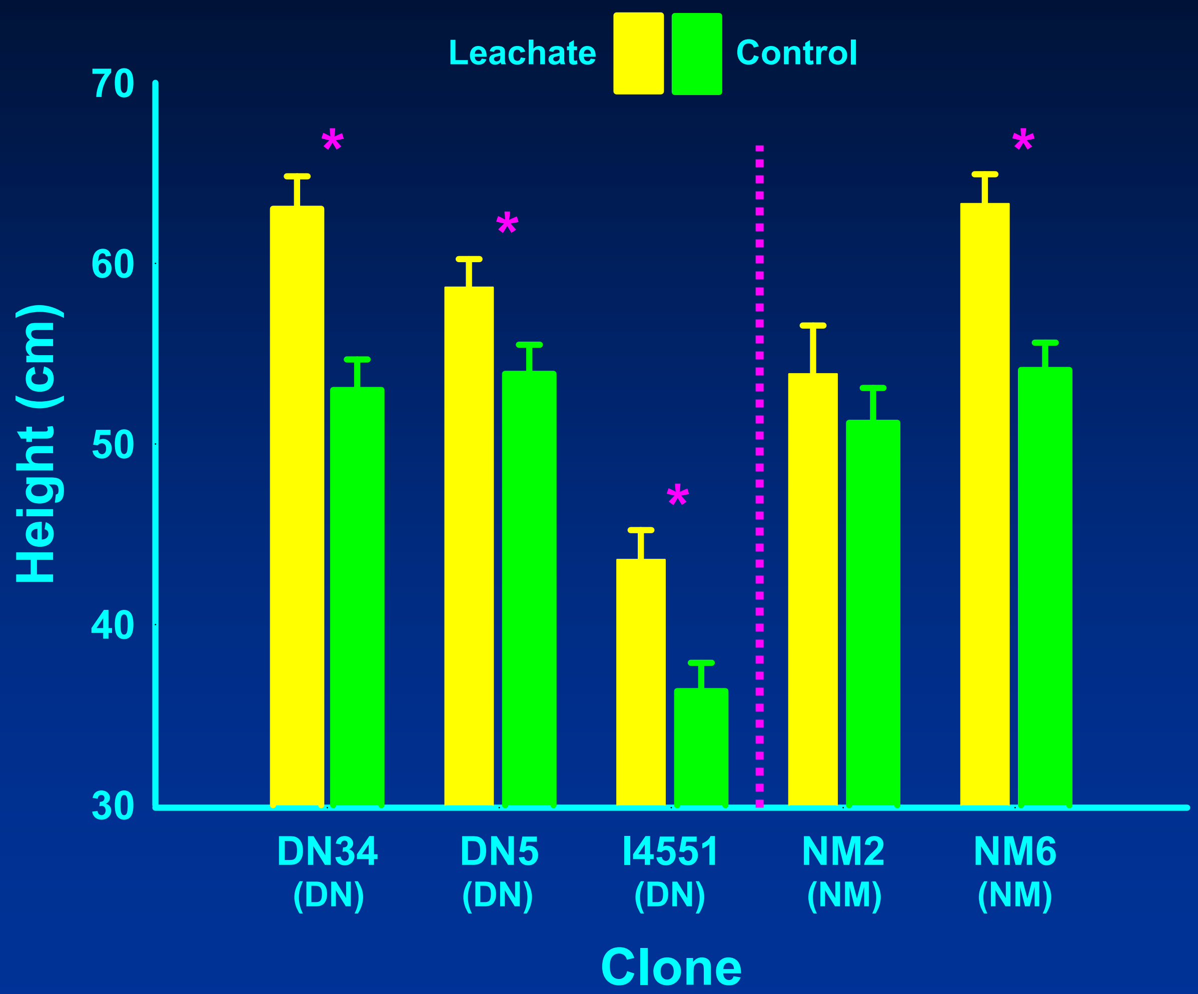
If variation due to the clone × contaminant interaction is strong, then clone performance is contaminant-dependent.

- Specific genotypes that perform well when irrigated & fertilized with designated contaminants.

Heavy Metals	Salts	Pesticides
A	A	A
B	B	B
C	D	E

Results – 70 Days After Planting

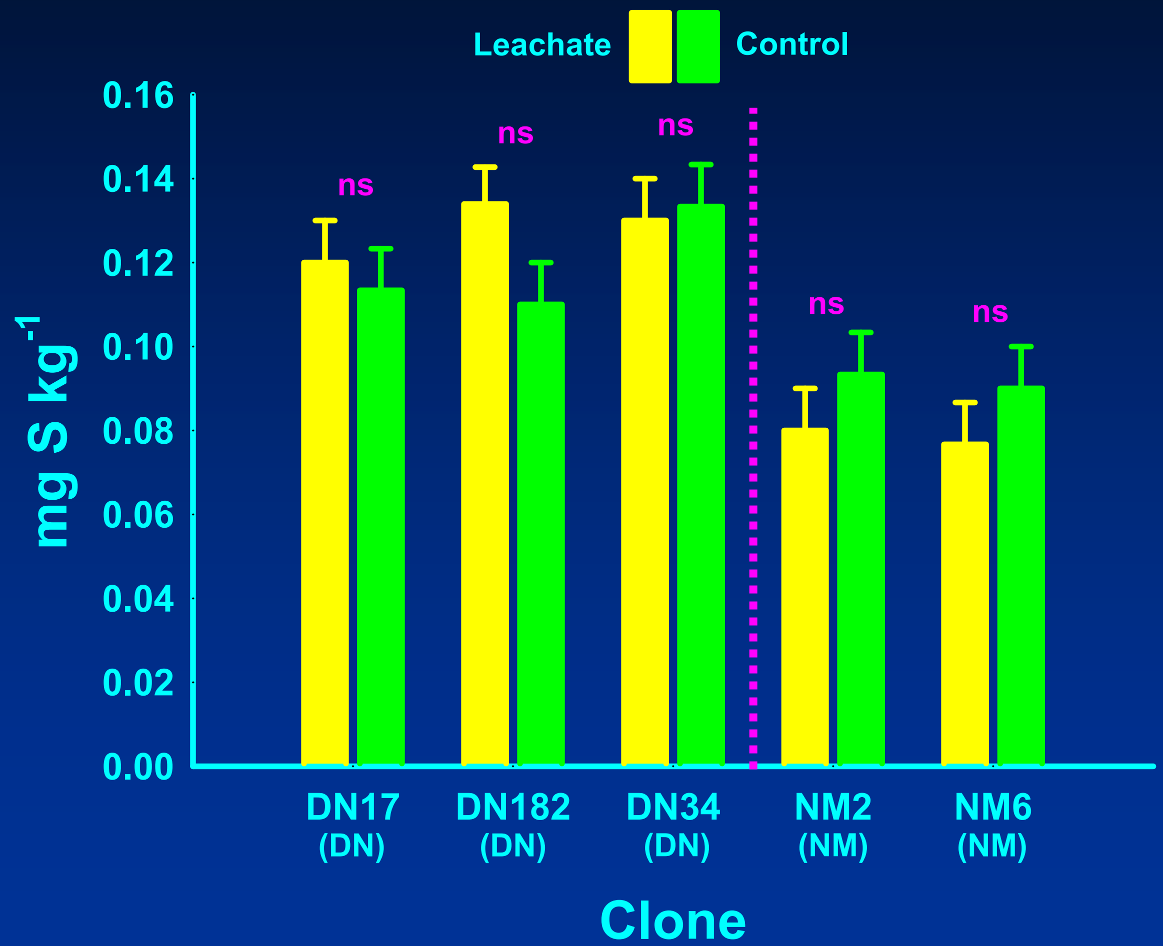
Height



Zalesny, R.S. Jr., Wiese, A.H., Bauer, E.O., Riemenschneider, D.E. Submitted. Establishment and growth of *Populus* hybrids treated with landfill leachate. Biomass Bioenergy

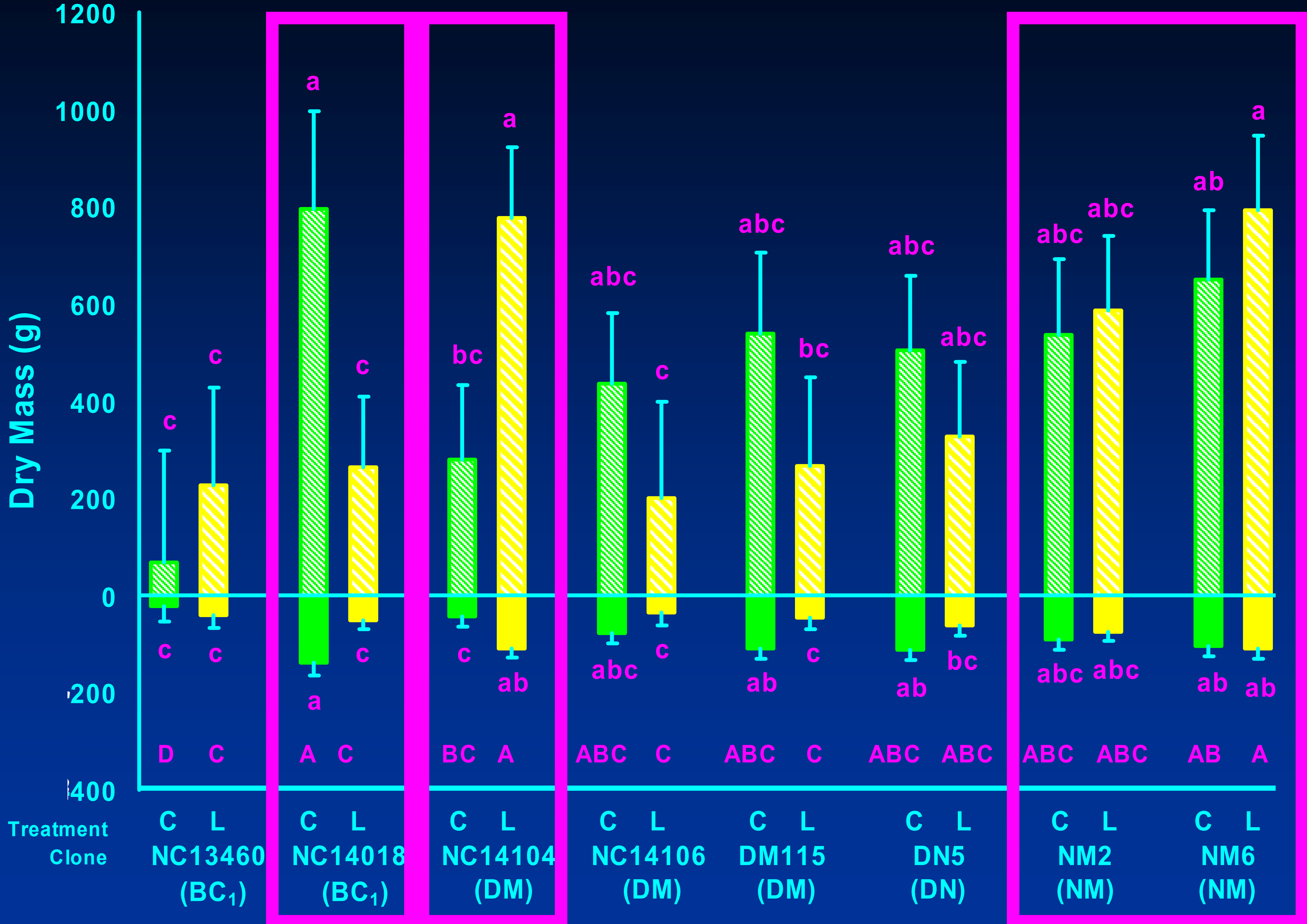
Results – One Growing Season

Root Concentration



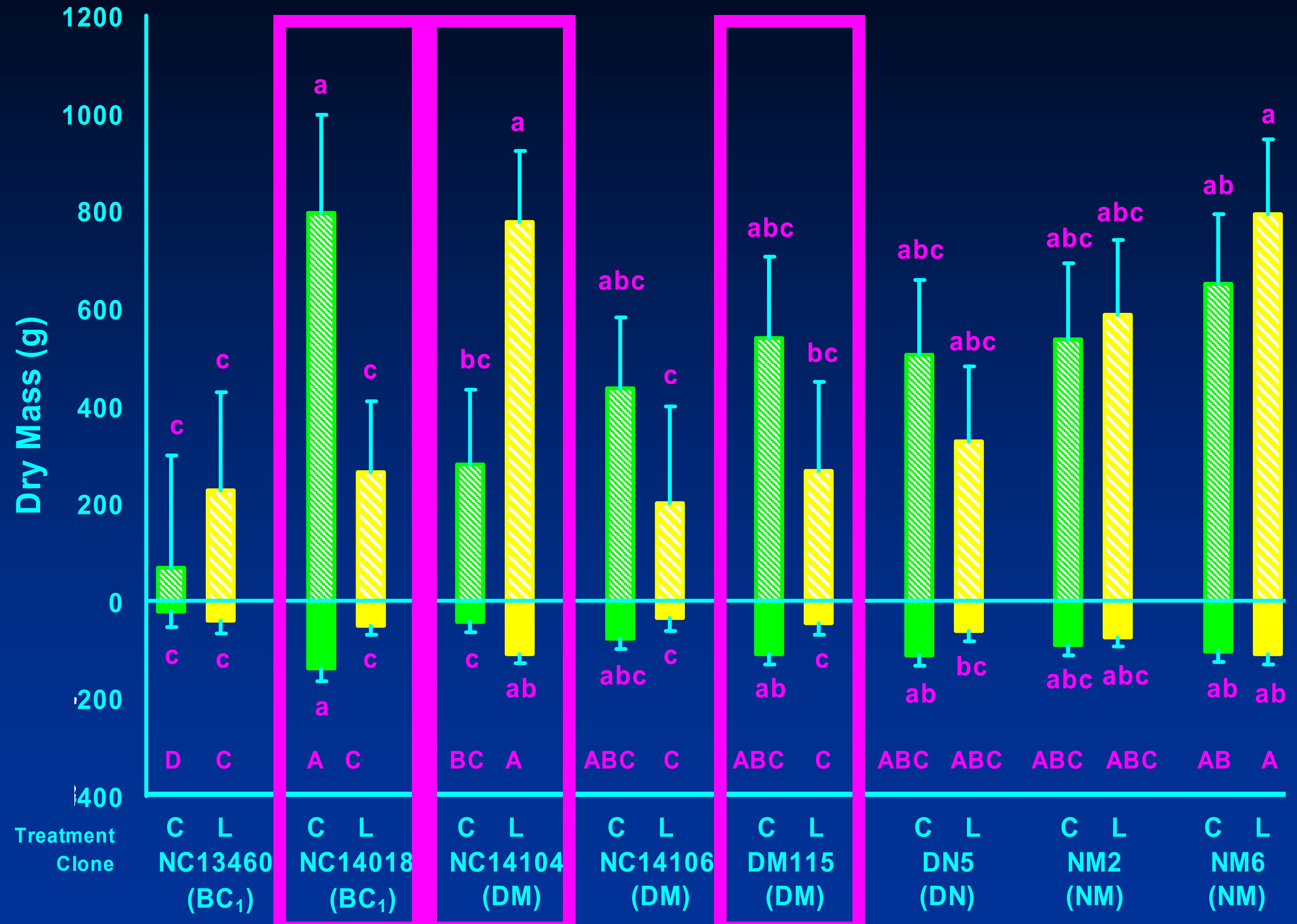
Zalesny, R.S. Jr., Bauer, E.O. 2007. Evaluation of *Populus* and *Salix* continuously irrigated with landfill leachate I. Genotype-specific elemental phytoremediation. International Journal of Phytoremediation 9:281-306.

Results – Aboveground Biomass (2 yrs)



Zalesny, J.A., Zalesny, R.S. Jr., Coyle, D.R., Hall, R.B. 2007. Growth and biomass of *Populus* irrigated with landfill leachate. Forest Ecology and Management 248:143-152.

Results – Belowground Biomass (2 yrs)



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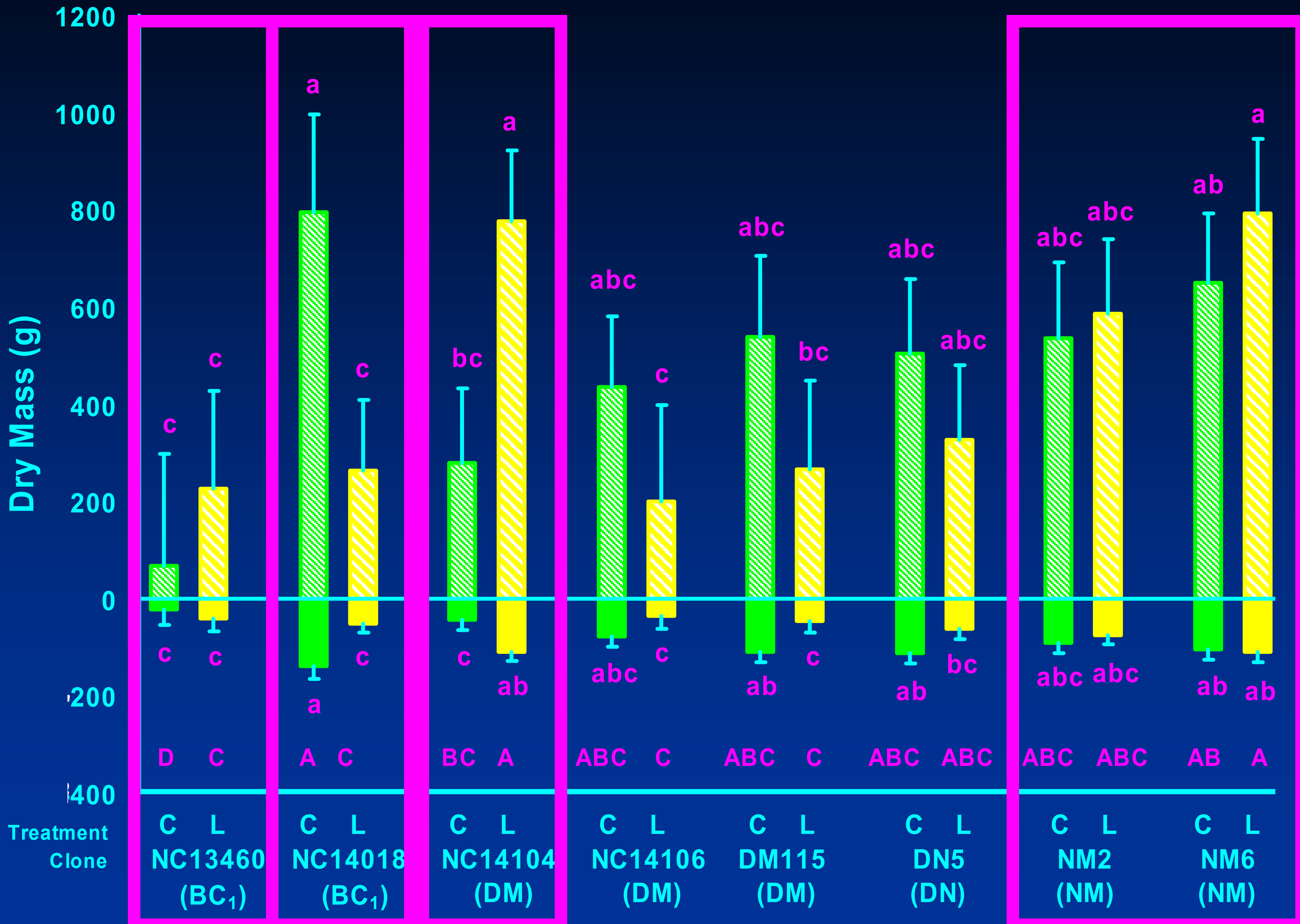
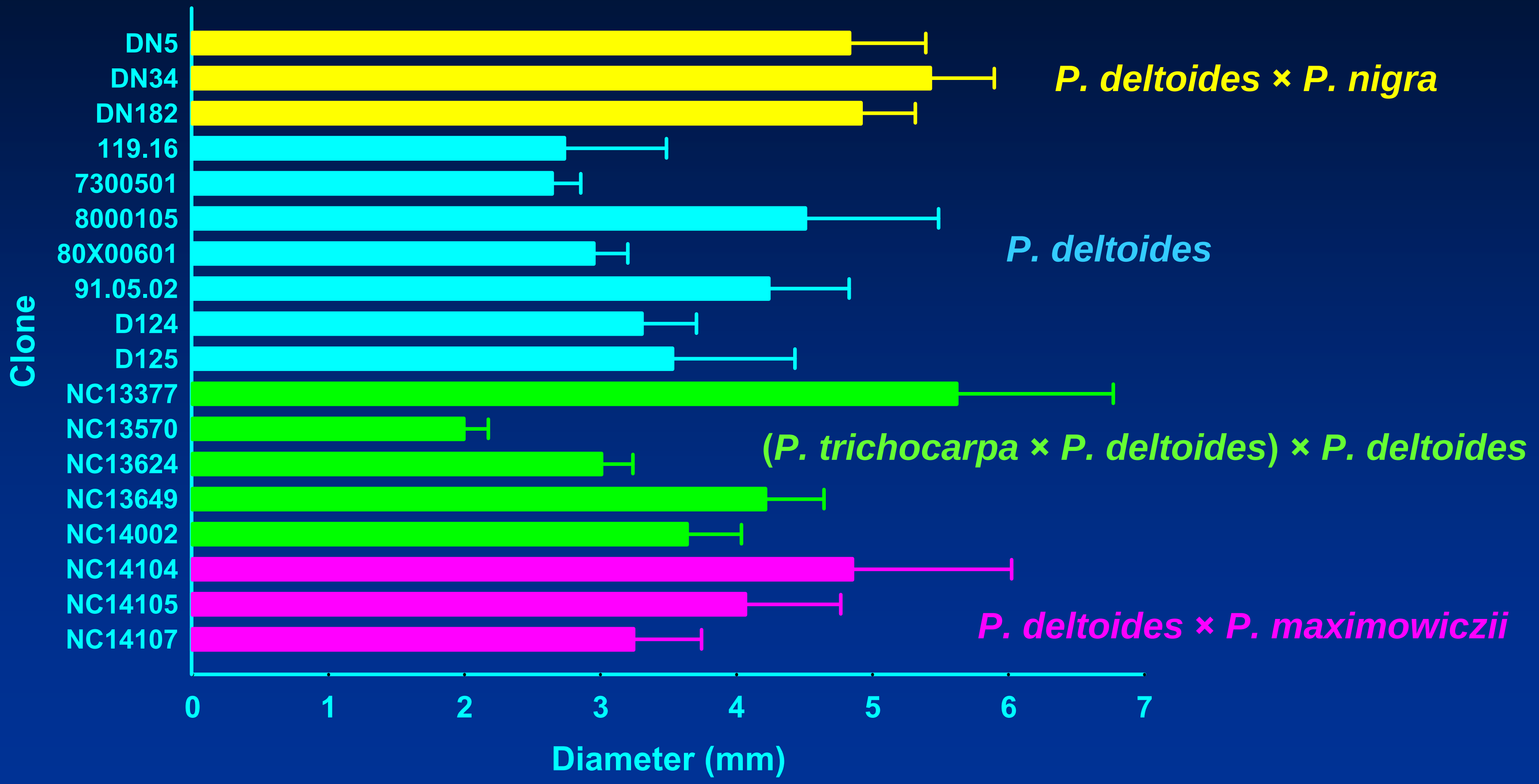
Results – Total Biomass (2 yrs)



Zalesny, J.A., Zalesny, R.S. Jr., Coyle, D.R., Hall, R.B. 2007. Growth and biomass of *Populus* irrigated with landfill leachate. Forest Ecology and Management 248:143-152.

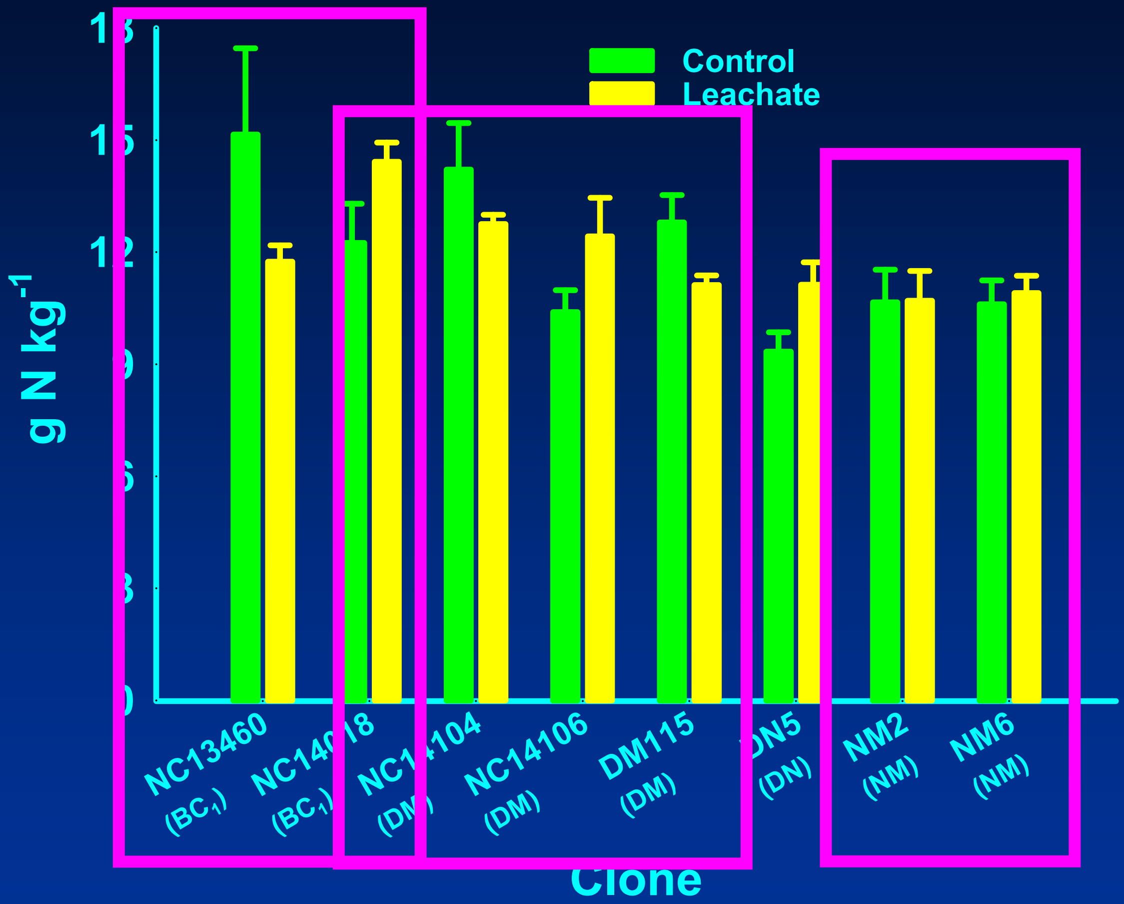
Results – One Growing Season

Diameter



Zalesny, R.S. Jr., Bauer, E.O., Hall, R.B., Zalesny, J.A., Kunzman, J., Rog, C.J., Riemenschneider, D.E. 2005. Clonal variation in survival and growth of hybrid poplar and willow in an *in situ* trial on soils heavily contaminated with petroleum hydrocarbons. International Journal of Phytoremediation 7:177-197.

Results – Woody Biomass (2 yrs)



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Practical Implications

- Short rotation woody crops are a viable option for helping to meet our nation's energy needs
- Proper genotypic selection is necessary for successful deployment of ecologically-sustainable phytotechnologies
- It is possible to combine intensive forestry with waste management to achieve dual goals of energy production & environmental benefits

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- Univ. of Wisconsin – Madison, Dept. Entomology (UWM)
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- Adam H. Wiese (USFS NRS)
- Richard B. Hall (ISU NREM)
- Bart T. Sexton (OCSWD)
- David R. Coyle (UWM)

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Questions?