Premature selection and inadequate testing of willow biomass varieties results in significant losses for growers.

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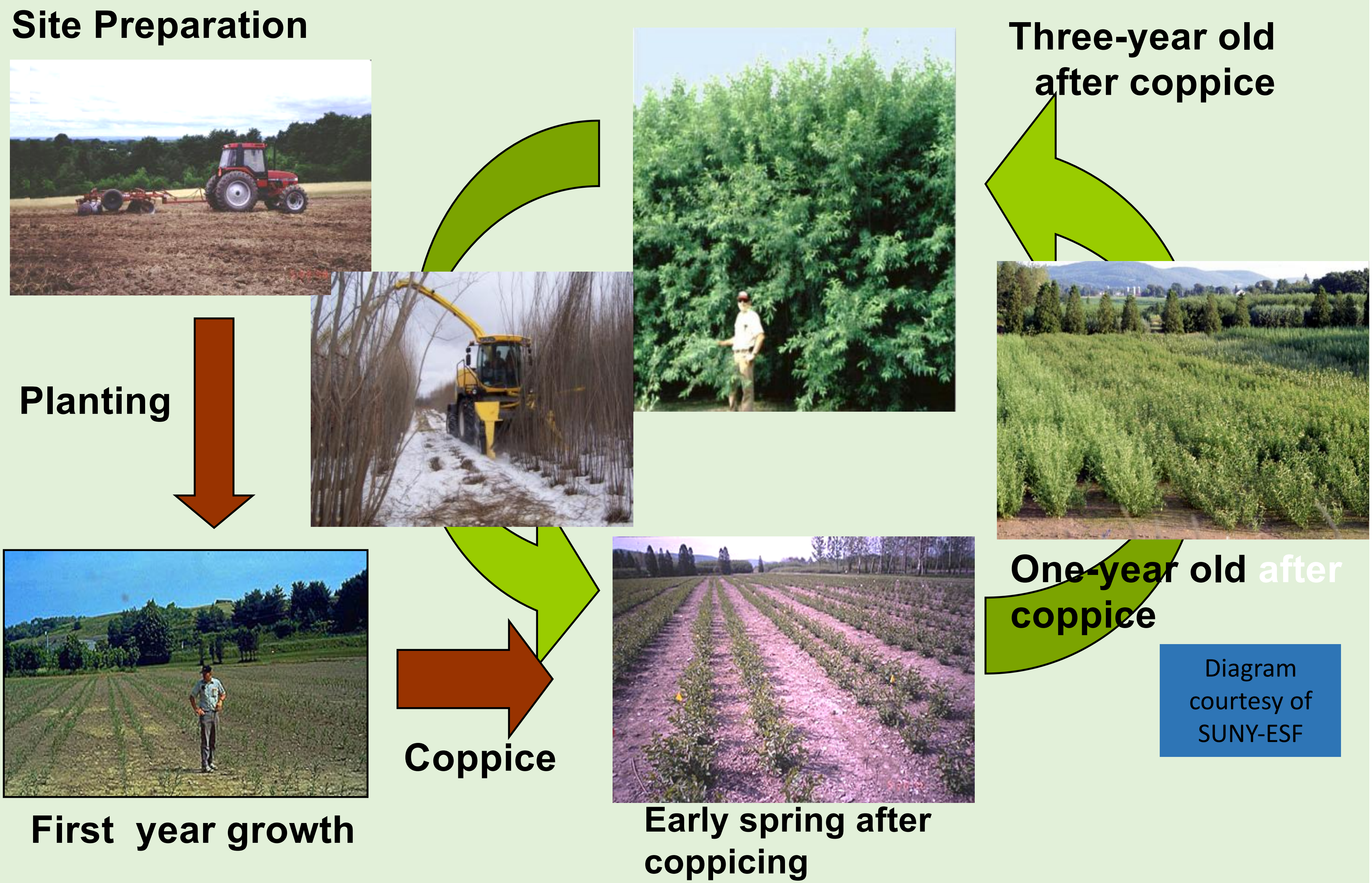
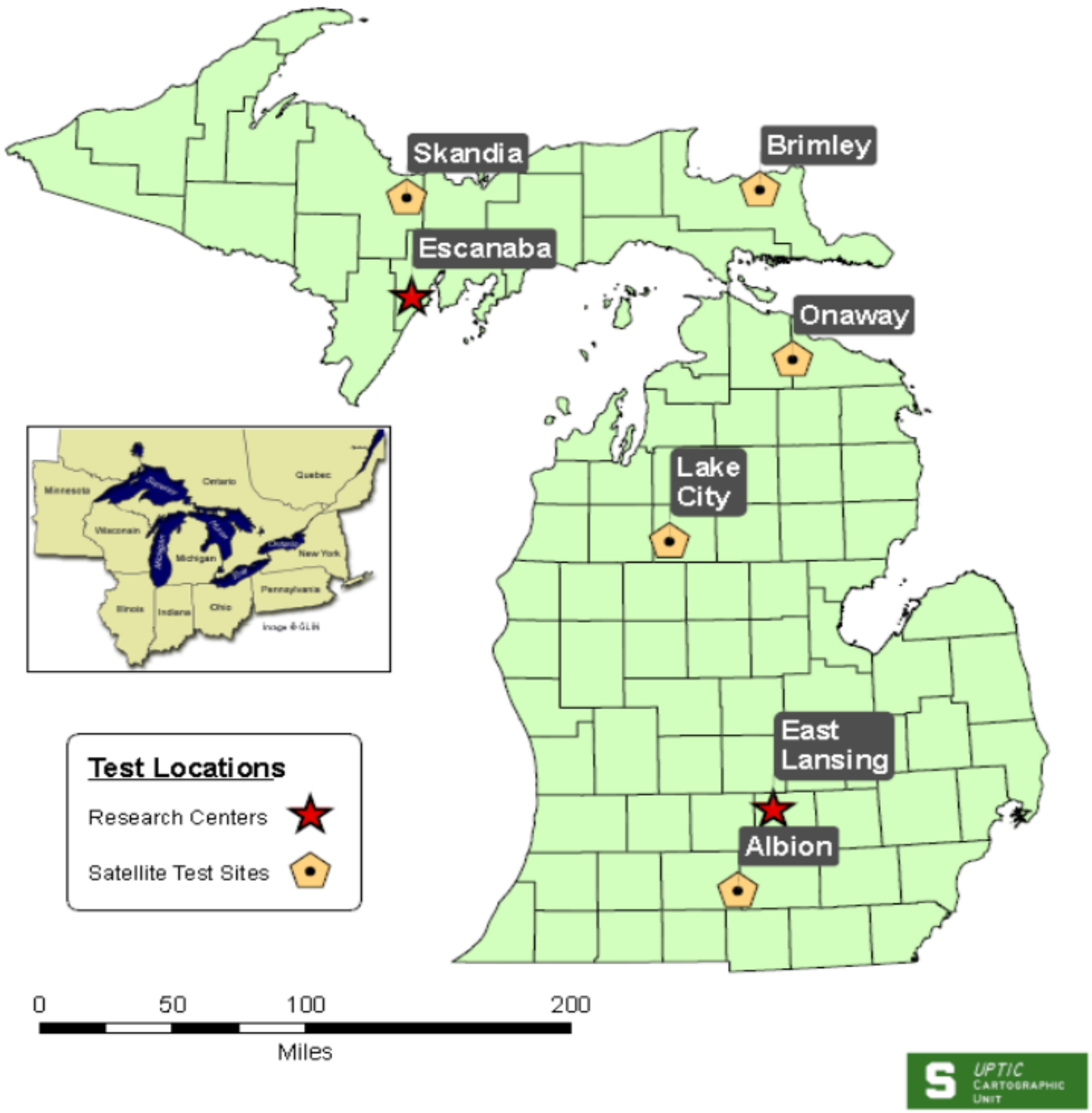
Willow Production System



Michigan State University's Network of Poplar and Willow Test Sites



The Test Plantations

Table 4: Planting and Harvest Dates of Willow Yield Trials in Michigan			
Test Site	*Planting Date*	*1st Harvest Date*	*2nd Harvest Date*
Escanaba, MI	5/26/2008	11/7/2011	10/16/2014
Skandia, MI	6/18/2009	10/22/2012	10/14/2015
Brimley, MI	6/23/2009	7/8/2013*	9/16/2015
Onaway, MI	5/20/2010	NA	NA
Lake City, MI	5/4/2010	10/23/2013	NA
Albion, MI	4/11/2011	11/4/2014	NA

*Note: This site was too wet to enter at the originally scheduled time for harvesting in the fall of 2012. Harvesting was delayed until the site dried sufficiently.

- 20 to 26 varieties at each site (33 total varieties tested).
- "Swedish" double-row planting design.
- 5,808 stems per acre.
- Randomized block design with 5 blocks at each site.
- 78 stools per plot.
- Double-row border: inner 18 stools were measured.
- Coppiced in year 1 then harvested on 3-year intervals.

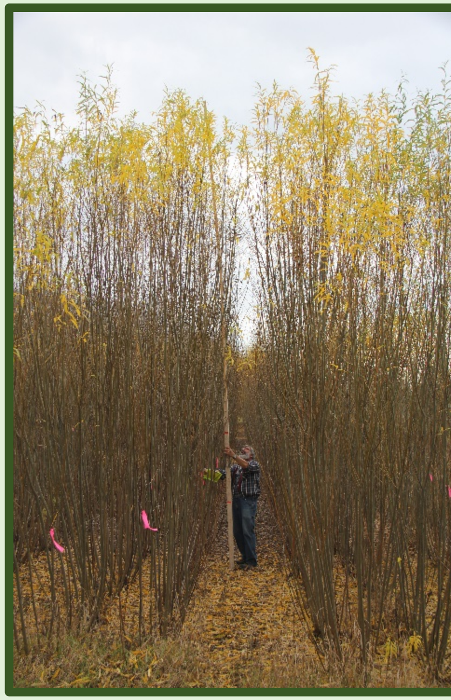


Table 6: Observations of pest pressure on various hybrid combinations of willow in a yield trial in Escanaba, MI. Leaf rust (*Melampsora epitea*) severity, Leaf hopper (*Empoasca fabae*) incidence, and browsing by deer (*Odocoileus virginianus)* are recorded along with total 7th-year dry biomass accumulation.

Hybrid Cross	*7-year yield (dry t/a)*	*Rust Severity*	*Plots with Leaf Hopper*	*Plots with Browsing*
Salix dasyclados	25	Rare		
Salix purpurea x miyabeana	25	Rare	25%	25%
Salix miyabeana	25	Rare		
Salix viminalis x miyabeana	22	Rare	84%	78%
Salix purpurea	22	Light		
Salix sachalinensis x miyabeana	19	Light	25%	33%
Salix eriocephala	5	Extreme	63%	88%

Table 9: Analysis of Variance (and broad sense heritability) Among 24 Willow Varieties
Growing in Replicated Yield Trials at Five Sites Across Michigan.
(All sites were harvested at least once, while three sites were harvested twice.)

Comparison of variance in 1st and 2nd rotation biomass yields at three sites for which data was available

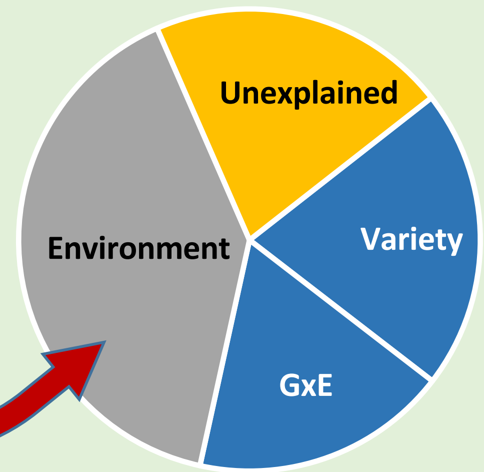
Source of Variation	DF	1st Rotation		2nd Rotation	
		% of Total Variance	H^2	% of Total Variance	H^2
Variety	23	6%	0.25	21%	0.34
Site	2	73%		38%	
Block-within-site	9	1%		2%	
Site-by-variety	36	5%		18%	
Error	198	15%		21%	

Analysis of variance in first rotation biomass yields at all five sites

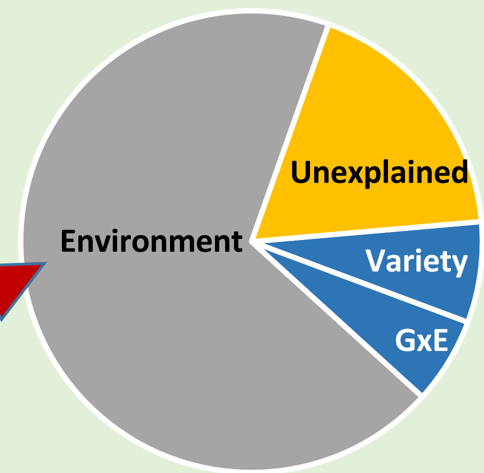
Source of Variation	DF	1st Rotation	
		% of Total Variance	H^2
Variety	23	7%	0.22
Site	4	66%	
Block-within-site	15	2%	
Site-by-variety	65	6%	
Error	249	18%	

Note: all terms in these analyses of variance were significant at the 0.0001 level.

Second Rotation – 3 Sites



First Rotation – 5 Sites



Willow Variety Biomass Production Relative to Best Variety at Each Site
Throughout a Network of 5 Yield Trials in Michigan

Variety	***Site Ranking After One Rotation***		***Site Ranking After Two Rorations***			***Average Score***	***Pedigree***	*Average Performance of this Pedigree*
	Albion	***Lake City***	***Escanaba***	***Skandia***	***Brimley***			
SX61	95%	62%	74%	97%	81%	82%	Salix miyabeana	85%
SX64	75%	71%	97%	100%	74%	83%		
SX67		81%	100%			91%		
Millbrook	91%	100%	93%	63%	73%	84%	Salix purpurea x miyabeana	77%
Oneida	74%	37%	91%	98%	70%	74%		
Oneonta	100%			91%	58%	83%		
Saratoga		42%	89%			66%		
Clone_L			81%			81%	Salix viminalis x miyabeana	73%
Fabius	89%	31%	87%	40%	83%	66%		
Otisco	80%		85%	74%	81%	80%		
Owasco	65%		75%	80%	58%	70%		
Taberg			76%			76%		
Truxton	75%	77%	76%	83%	52%	73%		
Tully Champion		88%	82%	76%	100%	87%		
Verona			58%	51%	58%	56%		
Canastota	98%		74%	76%	67%	79%	Salix sachalinensis x miyabeana	71%
Cicero	74%		61%			68%		
Marcy	86%		78%	69%	68%	75%		
Sherburne	64%	54%	62%	69%	57%	61%		
SV1	54%	46%	92%	55%	74%	64%	Salix dasyclados	64%
Allegany	61%	37%	64%	62%	58%	56%	Salix purpurea	62%
Boonville	78%	63%				71%		
FC185			85%	65%	44%	65%		
Fish Creek	80%	25%	98%	67%	41%	62%		
Onondaga			62%	69%	59%	63%		
Wolcott	55%	23%	78%			52%		
Clone_A			24%			24%	Salix eriocephala	26%
Clone_K		19%				19%		
S25		21%	14%		18%	18%		
S365		44%				44%		
Preble	89%					89%	Salix viminalis x (S. sachalinensis x S. miyabeana)	87%
Clone_C	92%	77%				85%		
Sheridan		96%				96%	Salix viminalis x (S. viminalis x S. miyabeana)	96%
Best Hybrid	*2.8 dry t/a-yr*	*1.7 dry t/a-yr*	*4.6 dry t/a-yr*	*3.0 dry t/a-yr*	*2.5 dry t/a-yr*			
Best 5 Hybrids	*2.7 dry t/a-yr*	*1.5 dry t/a-yr*	*4.4 dry t/a-yr*	*2.8 dry t/a-yr*	*2.1 dry t/a-yr*			

Green shaded cells show varieties with yields at least 75% of the best variety at each site.

Red shaded cells show varieties with yields less than 75% of the best variety at each site.

Yellow shaded cells represent good "General Performers" (highest Average score among those tested at 4 of the 5 sites)

Table 11: Yield Comparison among 5-variety cohorts - selected based on performance at different locations. Cohort composition was based on performance at each of 3 test locations as well as general performance across all three locations.

Yield of Cohort when planted in:	Five-Variety Cohort Composition							
	Top **Skandia** Cohort		Top **Brimley** Cohort		Top **Escanaba** Cohort		Top **Test-wide** Cohort	
	Variety	7-year yield (dry t/a)	Variety	7-year yield (dry t/a)	Variety	7-year yield (dry t/a)	Variety	7-year yield (dry t/a)
Skandia	SX64	17.90	Tully Champion	13.60	Fish Creek	12.00	SX61	17.40
	Oneida	17.60	Fabius	7.20	SX64	17.90	SX64	17.90
	SX61	17.40	Otisco	13.20	Millbrook	11.30	Millbrook	11.30
	Oneonta[1]	16.30	SX61	17.40	SV1	9.80	Otisco	13.20
	Truxton	14.80	SV1	9.80	Oneida[2]	17.60	Tully Champion	13.60
	Average	***16.80***	***Average***	***12.24***	***Average***	***13.72***	***Average***	***14.68***
Yield Loss Compared to Skandia Cohort			***27%***		***18%***		***13%***	
Brimley	SX64	11.10	Tully Champion	14.90	Fish Creek	6.10	SX61	12.00
	Oneida	10.40	Fabius	12.40	SX64	11.10	SX64	11.10
	SX61	12.00	Otisco	12.00	Millbrook	10.90	Millbrook	10.90
	Oneonta[1]	8.70	SX61	12.00	SV1	11.10	Otisco	12.00
	Truxton	7.70	SV1	11.10	Oneida[2]	10.40	Tully Champion	14.90
	Average	***9.98***	***Average***	***12.48***	***Average***	***9.92***	***Average***	***12.18***
Yield Loss Compared to Brimley Cohort	***20%***				***21%***		***2%***	
Escanaba	SX64	27.05	Tully Champion	22.87	SX67[2]	27.76	SX61	19.52
	Oneida	25.34	Fabius	24.07	Fish Creek	27.14	SX64	27.05
	SX61	19.52	Otisco	23.57	SX64	27.05	Millbrook	25.73
	Owasco[1]	20.77	SX61	19.52	Millbrook	25.73	Otisco	23.57
	Truxton	20.97	SV1	25.46	SV1	25.46	Tully Champion	22.87
	Average	***22.73***	***Average***	***23.10***	***Average***	***25.46***	***Average***	***23.75***
Yield Loss Compared to Escanaba Cohort	***11%***		***9%***				***7%***	
	1- Oneonta was not planted in Escanaba so Owasco was substituted for comparison.				2- SX67 was not planted at Skandia or Brimley so Oneida was substituted for comparison.			

Revenue lost by using varieties selected in distant tests.

Table 12: Comparison of yield and revenue in willow biomass plantations when varietal cohorts are chosen based on local test performance versus distant test performance. Yields are based on actual 7-year performance and annual regional losses asssume that 5,000 acres of commercial willow plantations are installed in a region and that willow biomass is worth $60/dry ton.

Planting Site	*Metric*	*Best Skandia Cohort*	*Best Brimley Cohort*	*Best Escanaba Cohort*	*Best Average Cohort*
Skandia	*Annual yield (dry tons/acre)*	2.8	2.0	2.3	2.4
	Annual revenue ($/acre)	$ 168	$ 120	$ 138	$ 144
	Annual regional loss ($)		$ (240,000)	$ (150,000)	$ (120,000)
Brimley	*Annual yield (dry tons/acre)*	1.7	2.1	1.7	2.0
	Annual revenue ($/acre)	$ 102	$ 126	$ 102	$ 120
	Annual regional loss ($)	$ (120,000)		$ (120,000)	$ (30,000)
Escanaba	*Annual yield (dry tons/acre)*	3.8	3.9	4.2	4.0
	Annual revenue ($/acre)	$ 228	$ 234	$ 252	$ 240
	Annual regional loss ($)	$ (120,000)	$ (90,000)		$ (60,000)

- Assuming 5,000 acres of commercial plantations in a region.
- Assume $60 per dry ton value for biomass (Billion Ton Report)

ANNUAL Losses compared to general performer cohort:
$30,000 - $120,000
ANNUAL Losses compared to selections from distant tests:
$90,000 - $240,000

Table 7: ESCANABA Willow Trial <u>Cumulative</u> Yields after 1, 4, & 7 Years
Ranked based on lifetime total yield
Units are dry tons/acre & rank number

Variety	*Yield Year 1*	*coppice Rank*	*Yield Year 4*	*1st Harvest Rank*	*Yield Year 7*	*Cumulative Yield Rank*
	dry tons/acre		*dry tons/acre*		*dry tons/acre*	
SX67	0.06	7	12.9	3	27.76	1
Fish Creek	0.04	12	12.8	4	27.14	2
SX64	0.05	10	12.4	10	27.05	3
Millbrook	0.03	18	12.8	5	25.73	4
SV1	0.06	8	12.7	7	25.46	5
Oneida	0.04	13	11.1	13	25.34	6
Saratoga	0.03	19	10.7	15	24.63	7
Fabius	0.07	2	11.8	11	24.07	8
FC185	0.03	20	12.5	9	23.73	9
Otisco	0.07	3	12.8	6	23.57	10
Tully Cham	0.07	4	13.6	2	22.87	11
Clone_L	0.06	9	11.6	12	22.56	12
Marcy	0.04	15	10.0	16	21.64	13
Wolcott	0.04	14	9.7	17	21.64	14
Taberg	0.04	16	10.9	14	21.14	15
Truxton	0.07	5	13.8	1	20.97	16
Owasco	0.07	6	12.6	8	20.77	17
Canastota	0.02	23	9.5	18	20.42	18
SX61	0.02	24	9.0	21	19.52	19
Allegany	0.08	1	9.4	19	17.78	20
Onondaga	0.04	17	8.6	23	17.24	21
Sherburne	0.03	21	8.9	22	17.13	22
Cicero	0.02	25	8.0	24	17.02	23
Verona	0.05	11	9.4	20	16.15	24
Clone_A	0.03	22	5.2	25	6.73	25
S25	0.01	26	3.5	26	3.81	26

Selction at age 1 captures 50% and at age 4 captures 70% of <u>top 10</u> performers.
Selection at age 1 captures none and at age 4 captures 60% of the <u>top 5</u> performers.

- Performance results from a single test location over 7 years.
- Only 3 of the top 5 varieties excelled after the first rotation (year 4).
- NONE of the top 5 varieties excelled at the time of the coppice cut (year 1).
- It takes time to identify elite varieties.

Revenue lost by selecting varieties prematurely.

Table13: Yield and value comparisons of willow crops grown at 3 sites in Michigan when 5-variety cohorts are selected from local tests after 1, 4, or 7 years. The best yields are achieved when selections are made from local tests after 7 years of observations (2 full rotations).

Trial Location	*5 Variety Cohort chosen after 7 years of testing*		*5 Variety Cohort chosen after 4 years of testing*				*5 Variety Cohort chosen after 1 year of testing*			
	(dry t/a)	*($/acre)*	*(dry t/a)*	*($/acre)*	*Lost Yield*	*Annual Lost Potential*	*(dry t/a)*	*($/acre)*	*Lost Yield*	*Annual Lost Potential*
Escanaba	26.6	$ 1,596	24.9	$ 1,494	-6%	$ (72,857)	21.8	$ 1,308	-18%	$ (205,714)
Skandia	16.8	$ 1,008	15.6	$ 936	-7%	$ (51,429)	14.4	$ 864	-14%	$ (102,857)
Brimley	11.0	$ 660	10.5	$ 630	-5%	$ (21,429)	10.9	$ 654	-1%	$ (4,286)

- Assuming 5,000 acres of commercial plantations in a region.
- Assume $60 per dry ton value for biomass (Billion Ton Report)

ANNUAL Losses if selections are made after only 1 rotation:
$21,000 - $73,000

Conclusions

1. *S. eriocephala* & *S. viminalis* hybrids were extremely susceptible to pests but pest pressure was uneven in time and space.
2. Biomass yield varied widely from site to site. 1st rotation yields ranged from 10.6 to 2.8 dry tons at Escanaba and Lake City, respectively.
3. 2nd rotation biomass yield averaged 31% greater than the 1st rotation yield across the network. In some places this increase was considerably greater.
4. Varieties changed rankings over time. Only 60% of the better varieties after 2 rotations were identifiable after only 1 rotation.
5. Selecting varieties prematurely can lead to ANNUAL revenue losses of $21,000 to $73,000 within a biomass producing region.
6. Selecting varieties from distant tests can lead to ANNUAL revenue losses of $90,000 to $240,000 within a biomass producing region.

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