FINAL REPORT:

REGIONAL FEEDSTOCK PARTNERSHIP – WILLOW IN MICHIGAN

Project Title:

Willow

Biomass crop feedstock development plan for 2012 for the Northeast and Midwest U.S.

Project Period:

October, 2009 through August, 2015

Agreement #3TB155

Between South Dakota State University and Michigan State University

Reported by:

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The Willow Biomass Yield Trial Network in Michigan

Willow research trials were located throughout Michigan in a network of six planting sites that span both peninsulas (Table 1 and Figure 1). The East Lansing location mentioned is the site of Michigan State University's main campus. Three trial sites are permanent research centers owned by Michigan State University and the other three were leased from others. Field equipment and staff were located at both the Escanaba and East Lansing locations. Naturally, more attention can be given to test plantations located nearest these two locations than at the others where the costs of transporting people and equipment limited the frequency of visits and length of time that could be spent. As a result, maintenance of plantations near Escanaba and East Lansing was generally superior to that at the satellite sites.

Site conditions varied considerably among these test locations. Soil conditions are summarized in Table 2 where, for example, pH is reported to range from 5.3 at Brimley to 7.4 at Onaway. Soil texture and drainage also varies considerably among sites. Climatic conditions at each site were monitored by on-site weather stations and also vary among sites. The growing season at Albion averages 38 days longer than at Skandia, for example. Table 3 is constructed to allow a comparison of site temperatures (by way of growing degree days) and moisture availability (by way of rainfall) during three distinct portions of each growing season. At some sites, less than 1/3 of the annual rainfall occurs during the portion of the year when air temperatures are most conducive for willow growth. This effects both plant growth (due to relatively dry summers) and field staff's ability to enter the sites to conduct cultural operations (due to excessively wet ground conditions in spring and fall).

There have been four sets of willow trials established in Michigan (Table 4). The first test began in 2002 in Escanaba and East Lansing. These contained 12 willow varieties and two poplar varieties for comparison. The second set of tests included 33 newer willow varieties (obtained from New York) and were established between 2008 and 2011 on six sites extending throughout the aforementioned trial network. The third regional trial included the most promising set of new varieties from New York and was established at only one site in 2012. The fourth group of plantings are large-plot blocks of single willow varieties and were established between 2010 and 2012. This latter group was established to provide sites for future harvesting and fertility studies.

The 2002 Willow Yield Trials

The earliest willow yield trials began in Michigan in 2002 at two locations in the state; East Lansing and Escanaba. Twelve willow and two poplar varieties were included in these high-density plantations (2' X 3' spacing yielding 7,260 stools per acre). The East Lansing location of this test was abandoned after the first 4-year rotation. During the first rotation, poplar at the southern site yielded an average 8.6 dry tons/acre-year which was 2.3 times the yield of poplar at the northern location during that same time. Willow at the southern location yielded an averaged 3.1 dry tons/acre-year and this was 3.1 times the yield of willow at the northern location. An analysis of these plantings by Wang and MacFarlane in 2012 determined that the difference in growing degree days between the two sites was the most significant environmental factor accounting for the difference in yield. This observation reinforces those made in an herbicide trial of two poplar varieties conducted at both of these locations in 1999. In that 2-year-long study, poplar varieties at the southern site produced twice as much height and diameter growth as those at the northern site. This is the source of the rule-of-thumb we use in Michigan: *Biomass yields in the southern part of the state will be approximately double those in the northern part of the state.* In this case the yield differential after the first rotation for poplar was 2:1 and for willow was 3:1. Willow productivity improved markedly after the first rotation at the northern site and we expect that this differential in willow productivity would have decreased in subsequent rotations. The southern test had was discontinued after one rotation, so data is unavailable to confirm this assumption.

The northern planting of this 2002 willow yield study has been harvested four times since its establishment. The Mean Annual Increment of poplar in these plots remained fairly constant for the first 3 rotations but declined in the fourth. The Mean Annual Increment of willow increased steadily with each of the first three rotations and plateaued during the fourth. Although the annual growth of willow was inferior to that of poplar during the early years of this trial, cumulative yields are now approaching parity with poplar. The best two willow varieties ("SX67" and "SX61") averaged 3.1 dry tons/acre-year while the top two poplar varieties ("NM5" and "NM6") averaged 3.3 dry tons/acre-year after 12 years (Table 5). Willow continues to grow increasingly well while poplar's vigor appears to be declining (Figure 2). We intend to follow this trial through one final rotation (harvesting in the fall of 2016) to confirm the trends.

The 2008 through 2011 Multi-site Network of Yield Trials

Willow varieties developed in New York (at both SUNY and Cornell) were tested at the six sites in our state-wide network. These trials were established between 2008 and 2011 (Table 4). Each replication of this trial included 20 or 26 of 33 total willow varieties. Plots were established using the "Swedish" double-row plantings design which yields a planting density of 5,808 stems per acre. Plots contained 78 stools but only the interior 18 stools were measured to obtain yield data. The test at the Onaway site experienced an extreme drought and the trees died. It was eliminated from analysis in 2013, leaving only five sites in this network. At the time of this report, three of the plantations were old enough to have been harvested twice. The remaining two have been harvested once.

<u>Establishment & Monitoring of the Network</u>

Sites at Skandia, Onaway, Lake City, and Albion were all prepared by spraying glyphosate (2-qts per acre). Brimley was not sprayed prior to planting due to logistical complications. When weeds were dead, all sites were then plowed and disked. Sites were finally rototilled (or spaded) immediately before planting.

All sites were laid out using the same procedure: standard 78-tree double-row plots, 26 varieties per block in Escanaba and 20 varieties per block at all other sites, and four blocks per site. Deer fencing was established at Skandia, Brimley, Onaway, and Lake City. The original fences were set on plastic posts using electrified rope powered by solar panels. The fences were set up with three wires on the inside and two on the outer posts, creating a three dimensional look. The two sets of posts and wire were separated by roughly four feet. Electrified high tensile fencing was already in place in Escanaba. Prior to harvest in 2012 the fences in Skandia and Brimley were both removed. In 2011 fencing was re-done in Onaway and Lake City. The fence in Lake City was completely replaced with a more permanent 8' tall woven plastic mesh fence. The Albion site was enclosed by a similar 8' tall woven plastic mesh fence from the outset. In 2015 the fence in Lake City was again altered, the majority of the mesh fence was removed and replaced with solar powered electric lines.

Soil samples were collected from each of the four blocks at all of the locations during the summer of 2012 and analyzed for organic matter, pH, P, K, and Ca by Agro-One Soil at Cornell University (results in Table 2). Continuously recording weather stations were placed at each site and temperature, precipitation, and relative humidity data was retrieved at regular intervals throughout each growing season. A summary of these data appears in Table 3.

Extreme drought during the summer of 2013 at the Onaway site caused the death of the willow trial there.

Measurements Throughout The Network

All quantitative data collected was summarized and reported annually in reports to South Dakota State University and posted to the Knowledge Discovery Framework (KDF) in the winter following each growing season.

In **year one** each plantation was monitored for herbicide effectiveness and spot-treated accordingly if needed. All sites were scored for leaf rust, insect damage, and survival. At the end of the first growing season all stems were cut (coppiced) to encourage multiple-sprouting on each stool the following year. Stems cut from the inner 18 trees of each 78-tree plot were oven-dried and their mass was recorded.

In **year two** all plantations were scored for leaf rust, insect damage, and survival. Skandia, Brimley, Onaway, and Lake City were all mowed and/or cultivated between the double row pairs to reduce weed growth. Diameters of all the stems in these 18-stool sample plots were measured and four of the tallest stem heights in each sample plot were recorded at the end of the second growing season.

In **year three** leaf rust, insect damage, and herbivore damage were recorded.

Year four was the final year of the first rotation. Plantations were harvested at the end of the fourth growing season. Measurements at the time of harvest were made of the 18-stool sample plots. Measurements included: plot survival, height of tallest stem on four of the stools in each sample plot, number of stems per stool on the same four stools in each sample plot. The green weight of the chips harvested from each 18-stool sample plot was recorded. A sub-sample was collected for each sample plot, which was oven-dried to obtain dry weight and moisture content for the chips taken from that plot.

The second rotation comprised **years five, six, and seven**. Insect damage, herbivore damage, and the presence of leaf rust was annually monitored during this time. Data collection and harvesting was conducted in **year seven** using the same procedure followed in year four. At the time of this report, the Escanaba, Skandia, and Brimley had been harvested for the second time (Table 6).

Analysis of Growth Across the Network

Significant differences were observed in biomass yield (1) among planting sites, (2) among varieties, and (3) within planting sites. Significant interactions between varieties and planting sites were also observed. All five of the surviving trials in this network had been harvested at least once. The majority of the variance in first rotation biomass yields was due to site effects (66%) but there was sufficient variation among varieties (7%) to accommodate yield improvement through breeding and selection (Table 7). Unfortunately, 6% of the variation was attributed to genotype by environment interaction; meaning that there was a great deal of site specificity to varietal performance. A comparison of variance in first rotation yields with that in the second rotation was performed for the three sites in which those data were available. The proportion of variation due to site effects decreased markedly between the first and second rotations, dropping from 73% to 38% (Table 7). It will be interesting to see if this trend continues if we are able to harvest the two remaining sites in the network for a second time.

It is wise to plant cohorts of several varieties in commercial production plantations to ensure against loss due to pests. For willow, it has been suggested that these cohorts contain at least five different varieties. Strong genotype by environment interactions cause certain varieties to perform well everywhere while other varieties only perform well at specific sites. Cohorts can be composed of varieties that perform well across the entire region (good ***general*** performers), of varieties that perform well in local tests (good ***local*** performers), or of varieties that perform well in remote tests (good ***distant*** performers). Cohort performance tends to improve when selections are based on tests done near to the place where they are planted.

The relative performance of all varieties throughout this network was summarized (Table 8). “SX61”, “SX64”, “Millbrook”, “Otisco”, and “Tully Champion” performed in the upper quartile at most of the sites where they were tested. Although they were rarely the most outstanding performers at any of the sites, together they formed the best ***general*** performing cohort for Michigan.

It was possible to compare the performance of this cohort of ***general*** performers with cohorts composed of good ***local*** performers at each of several sites (Table 9). ***General*** performers yielded from 2% (at the Brimley site) to 13% (at the Skandia site) less biomass than good ***local*** performers after two rotations. Greater yield reductions would have resulted if cohorts were selected based on their performance in remote test locations. Cohorts of good ***distant*** performers yielded from 9% to 27% less biomass than cohorts of good ***local*** performers (Table 9). Choosing the wrong cohort, because of inadequate testing, produces less biomass than would otherwise be possible and decreases financial returns to growers. The small investment needed to conduct adequate testing is more than offset by the increased productivity of properly chosen cohorts.

As we previously observed in the 2002 yield trials, yield here also increased between the first and second rotations. The top-five-variety cohort’s yield increased modestly at the Escanaba site (10%) intermediately at the Brimley site (34%) and extraordinarily at the Skandia site (193%).

Varietal ranking also changed over time so the composition of the top-five-variety cohort changed between the first and second rotations. Selecting early at both the Escanaba and Skandia sites would have resulted in a 7% loss in yield. So, willow variety performance varies in both space and time. Adequate testing therefore requires observations on many sites over multiple rotations. Failure to test adequately can reduce yields significantly.

The 2012 Cornell Willow Yield Trial

A 24-variety yield trial was established in 2012 at the Escanaba site as part of a regional test of 14 of the newest willow hybrids developed at Cornell. The other ten varieties in this test had been previously included in yield trials in Michigan. Eight of these older varieties had been tested in the 2008 Escanaba willow yield trial that was immediately adjacent to this newer trial. The 2012 trial was established and measured following the same protocols already described for the yield trials that were established between 2008 and 2011, however no coppice cut plot weights were recorded in this trial. Plots in the 2012 trial were smaller than those in the earlier trials: Whole plots contained 48 stools (rather than 78) and measurement plots were composed of 16 stools (rather than 18).

First rotation average biomass yield of the top five varieties in the 2012 trial (16.0 dry tons/acre) was 22% better than the top five varieties in the 2008 trial (13.1 dry tons/acre). Except for Millbrook, the remaining top five performers in the 2012 trial were varieties that had been developed subsequent to the 2008 test. Interestingly, the proportional yields of varieties common to both trials was not consistent (Table 10). For example, Saratoga was the top performer in the 2012 trial (16.6 dry tons/acre) but only yielded 10.7 dry tons/acre (78% of the best performer) in the 2008 trial. Also, although Tully Champion's proportional ranking changed in the two tests, its actual yield was approximately the same (13.5 – 13.2 dry tons/acre in 2008 and 2012 respectively). Part of the differences in yield observed here must be attributed to the breeding, testing, and selection of new hybrids. But a large portion of the variation observed between the tests is due to within site variations in soil conditions and in climatic differences between the growing seasons over which yield measurements were taken.

Understanding how different varieties behave under a range of conditions allows for the establishment of confidence limits on yield projections. Testing willow on multiple sites over a series of growing seasons is critical to understanding the variation that commercial growers will face.

Reporting

The analysis of these data has been summarized in several presentations made to professional organizations and is still underway:

Miller, R.O. 2016. Premature selection and inadequate testing of willow biomass varieties results in significant losses for growers. Presented at 11th Biennial Short Rotation Woody Crops operations Working Group Conference, Fort Pierce, FL, October 11-13, 2016.

Miller, R.O. and B.A. Bender. 2014. Twelve-year productivity of willow and poplar clones in a high density energy plantation in Escanaba, Michigan, USA. IN Proceedings. International Poplar Symposium VI, Vancouver, British Columbia, Canada, July 20-23, 2014.

Miller, R.O., D. Keathley, and P. Bloese. 2012. Early results from *Populus* and *Salix* clonal yield trials at six locations in Michigan, USA. A poster presented at the 24th session of the International Poplar Commission. October 30 – November 2, 2012, Dehradun, India.

Keathley, D., R. Miller, and P.Bloese 2012. Initial willow biomass yield trial results for Michigan. Presented at the Sun Grant Initiative 2012 National Conference, New Orleans, LA, October 2, 2012.

Nikiema, P., D. Rothstein, and R. Miller, 2012. Initial greenhouse gas emissions and nitrogen leaching losses associated with converting pastureland to short-rotation woody bioenergy crops in northern Michigan, USA. Biomass and Bioenergy 39:413-426.

Wang, Z. and D.W. MacFarlane, 2012. Evaluating the biomass production of coppiced willow and poplar clones in Michigan, USA, over multiple rotations and different growing conditions. Biomass and Bioenergy 46:380-388.

Miller, R.O., D.W. MacFarlane, D.E. Rothstein, and Z. Wang. 2010. Energy crop plantation system development for Salix and Populus in Michigan, USA. IN: Poplars and willows: from research models to multipurpose trees for a bio-based society. Proceedings of the Fifth International Poplar Symposium, Orvieto, Italy, September 20-25, 2010.

Closing Observations

Growers ask three simple questions: 1) "What should I plant?" 2) "How should I manage it?" and 3) "Will I make money if I do that?" The short answer is; "It depends." That is not very satisfying, but true. In reviewing the plot yield data reported here, it becomes obvious that yield depends on many factors including:

1. Variety selection. Choosing appropriate genotypes for specific sites is critical and can account for five-fold differences in yield from one place to another. Approximately 20% of the variability seen in these trials was due to genetic variation among varieties. Another 20% of the variation was due to genotype X environment interaction among the varieties and planting sites – meaning that there will never be one best variety or set of varieties for universal use. Observations of clonal resistance to pests has not been presented here but was reported in Miller, 2016 and is substantial. Yield of the better varieties averaged about 3 dry tons/acre-year across the network. Yield of locally selected varieties surpassed yield of those selected in distant trials. As new varieties are produced and commercialized, these yield projections will change substantially, so an expressed yield of 3 dry tons/acre-year of a tired-old variety can easily be surpassed by those being produced today.

2. Site fertility and soil moisture availability. 40% of the variability in yield observed was due to differences among or within the planting sites. This was probably due to a combination of edaphic and climatic factors but this trial design does not allow for further partitioning of this variance component. All of our trials are un-fertilized and un-irrigated but they have been placed on sites with substantially different fertility and moisture regimes. Fertilizer trials of willow have not been done in Michigan. It is expected that fertility and water management can be employed to increase yields, but the impact of these management systems on feedstock production Life Cycle Analysis remains undocumented.

3. Spatial and annual climatic variation. As previously mentioned, the length and conditions within the growing season can account for more than 3-fold difference in growth from one place to another. Annual climatic anomalies can produce equally impressive differences from one growing season to the next. A spectacular growing season during 2010 in Escanaba resulted in exceptional growth that year. The reverse occurred during the 2012 growing season at the Albion site where a draught caused growth to nearly stop that year. These seasonal anomalies are unpredictable but have serious implications for growth and yield. A draught at the Onaway site in 2013 caused the complete death of the willow trial there. These events demonstrate the risk that growers assume if they choose to produce willow biomass. The lack of insurance against yield losses is a major barrier to commercialization of this production system.

4. Stand development characteristics. High density willow plantations rely on frequent harvests to maintain cash flow and on the coppicing of the cut stumps to provide plants for the next rotation. Poplar hybrids have been grown in this same way but willow seems to survive repeated harvests better. In one of our trials, poplar out yielded willow in the first three rotations, but began to fall behind in the fourth. Willow yield increases with each subsequent rotation while poplar does not. Varieties selected in the early development of

high density willow stands yield less than those selected after the stand has matured.

5. Influence of damaging agents. Certain willow varieties demonstrate a higher susceptibility to diseases, insects, and browsing animals. These pests did not exert uniform pressure across the entire trial network and so a thorough analysis was not possible. Where these pests did occur, it was clear that varieties having *Salix viminalis* as one of the parents did not fare well (Miller, 2016). On the whole, willow varieties are generally more resistant to pests than are many of the poplar varieties available today for use a biomass crops in the Midwest.

6. Weed competition. Among the damaging agents, weeds deserve to be singled-out and belabored (if not eradicated). The most common and non-variety-specific cause of yield loss in energy plantations is weeds. Controlling weeds is expensive and sometimes the most difficult aspect of plantation culture so it is frequently not given the attention it should get. Even by seasoned professionals (like us). Inadequate site preparation and the difficulty of removing weeds from young established plantations are the two most common causes of yield loss to weeds – not to mention plantation failure.

7. Making Money. Successful willow production depends on growers learning and implementing an entirely new silviculture system. It also requires specialized planting and harvesting equipment that can be exceptionally expensive to purchase. In addition, the crop itself can only be harvested during a brief time in the fall and winter and it produces small pieces of stems that contain a high ratio of bark to wood. This means that an end-user must be willing to buy and use material of this quality and at the times it is available. The combination of specialized growing systems, specialized equipment, and unique feedstock quality combine to make this system difficult to successfully implement. It has been done however in various parts of the world, and the simulation models predict that it can be done here as well.

TABLE 1: Willow Biomass Trial Plantation Locations in Michigan				
Site Name	**Location in Michigan**	**Latitude**	**Longitude**	**Site Owner**
Albion	Albion, MI, Calhoun Co.	42º 11’ 32.64” N	84º 44’ 4.20” W	Michigan State University
Brimley	Brimley, MI Chippewa Co.	46º 24’ 2.25”N	84º 28’ 4.30”W	Chippewa – E. Mackinac Conserv. Dist.
Escanaba	Escanaba, MI Delta Co.	45º 46’ 10.65”N	87º 12’ 2.44”W	Michigan State University
Lake City	Lake City, MI Missaukee Co.	44º 17’ 54.39”N	85º 12’ 23.49”W	Michigan State University
Lansing	East Lansing, MI Ingham Co.	42º 40' 12.37" N	84º 27' 50.20" W	Michigan State University
Onaway	Onaway, MI Presque Isle Co.	45º 22’ 53.36”N	84º 14’ 31.01”W	Mark McMurray
Skandia	Skandia, MI Marquette Co.	46º 21’ 42.77”N	87º 14’ 39.21”W	Barry Bahrman

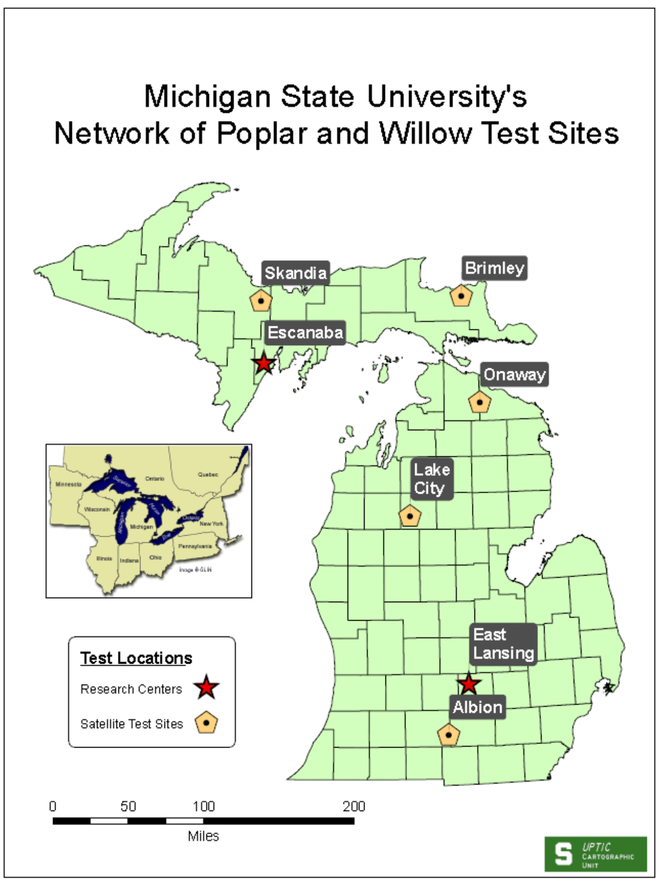

TABLE 2: Soil Conditions at the six trial sites in the Michigan network							
	Soil Analysis from Agro-One @ Cornell					*NRCS Soil Survey*	
Site *Test Plantation*	*Organic Matter (%)*	*pH*	*P (lbs/ac)*	*K (lbs/ac)*	*Ca (lbs/ac)*	*Soil Series*	*Drainage Class*
Albion						Hillsdale sandy loam	Well drained
2011 20-variety Willow Yield Trial	2.0	6.31	11.2	256	1467		
Brimley						Biscuit very fine sandy loam & Rudyard silt loam	Somewhat poorly drained
2009 20-variety Willow Yield Trial	4.0	5.25	2.0	139	1999		
Escanaba						Onaway fine sandy loam	Moderately well drained
2008 26-variety Willow Yield Trial	2.8	6.10	2.0	61	2017		
2012 24-variety Willow Yield Trial	2.5	6.98	23.5	142	2689		
Lake City						Emmet – Montcalm complex (sandy loam)	Well drained
2010 20-variety Willow Yield Trial	1.9	6.58	2.3	86	1534		
Onaway						Bonduel loam	Somewhat poorly drained
2010 20-variety Willow Yield Trial	3.4	7.28	3.5	159	5514		
Skandia						Munising fine sandy loam	Moderately well drained
2009 20-variety Willow Yield Trial	3.6	6.48	2.0	83	2522		

Precipitation, growing degree days, and growing season length at each of six field test sites.
Data for certain years at particular sites are missing because weather stations had not yet been installed or malfunctioned.
Data in *"italics"* were obtained from a nearby automated weather station.

Planting Site	Year	Growing Season Totals			Spring (3/21 - 6/20)			Summer (6/21 - 9/20)			Fall (9/21 - 12/20)		
		Rain (in.)	Growing Degree Days (base 50°F)	Growing Season Length (days)	Rain (in.)	Growing Degree Days (base 50°F)	Days in Season	Rain (in.)	Growing Degree Days (base 50°F)	Days in Season	Rain (in.)	Growing Degree Days (base 50°F)	Days in Season
Albion	2011	28.6	3007	188	*9.2*	*775*	*68*	12.2	1974	90	7.2	258	30
	2012	19.3	3265	178	6.1	963	63	5.8	2098	92	7.4	204	23
	2013	14.4	2802	171	4.8	702	53	3.1	1852	92	6.5	248	26
	2014	22.3	2600	169	9.6	746	52	*8*	*1652*	*92*	4.7	202	25
	2015	11.9	2939	184	4.8	808	57	2.6	1797	92	*4.5*	334	35
	Ave.	***19.3***	***2923***	***178***	***7***	***799***	***59***	***6***	***1875***	***92***	***6***	***249***	***28***
Brimley	2010	23.7	2105	206	6.9	647	73	9.9	1285	92	6.9	173	41
	2011	14.8	1961	186	2.2	459	58	5.1	1268	92	7.5	234	36
	2012	11.5	2098	188	1.9	632	67	2.5	1334	92	7.1	*132*	29
	2013	29.6	1390	131	5.3	227	31	14	1094	86	10.3	*69*	14
	2014	15.7	1134	117	7.0	231	29	0.1	865	81	8.6	*38*	7
	2015	16.2	1381	143	*2.7*	*203*	*29*	6.3	1074	85	7.3	*104*	29
	Ave.	***18.6***	***1678***	***162***	***4***	***400***	***48***	***6***	***1153***	***88***	***8***	***125***	***26***
Escanaba	2009	20.3	1893	192	8.5	445	62	5.1	1292	92	6.7	156	38
	2010	28.1	2476	214	7.6	674	78	12.8	1539	92	7.7	263	44
	2011	23.6	2234	198	9.4	469	59	7.5	1525	92	6.7	240	47
	2012	21.2	2407	204	7.3	692	77	7.0	1545	92	6.9	170	35
	2013	22.9	2055	183	5.4	457	58	10.0	1404	92	7.5	194	33
	2014	31.0	1869	184	8.9	480	59	13.5	1229	92	7.2	156	33
	2015	22.4	2214	206	8.8	496	67	7.6	1448	92	5.4	264	47
	Ave.	***24.2***	***2164***	***197***	***8***	***530***	***66***	***9***	***1426***	***92***	***7***	***206***	***40***
Lake City	2010	24.4	2456	189	*7.6*	*838*	*82*	*12.8*	*1503*	*89*	4.0	115	18
	2011	23.9	2032	142	11.2	433	38	4.9	1453	85	7.8	146	19
	2012	23.3	2249	169	*8.5*	*818*	*74*	*8.2*	*1360*	*85*	6.6	71	*10*
	2013	22.4	1895	151	8.7	444	41	6.7	1343	86	*7.0*	*108*	*24*
	2014	26.3	1906	220	11.5	451	44	*7.1*	*1292*	*92*	*7.8*	*164*	*84*
	2015	17.4	1807	176	*9.1*	*420*	*84*	*8.3*	*1387*	*92*	*NA*	NA	*NA*
	Ave.	***23.0***	***2057***	***175***	***9***	***567***	***61***	***8***	***1390***	***88***	***7***	***121***	***31***
Onaway	2010	24.6	2535	194	*9.8*	*801*	*79*	*9.9*	*1554*	*92*	*4.9*	180	*23*
	2011	31.5	2035	142	11.8	412	37	9.3	1455	86	10.4	168	19
	2012	18.8	2323	146	8.0	561	44	2.7	1542	*90*	8.1	220	*12*
	2013	12.4	1829	142	6.6	376	41	0.2	1344	*82*	5.6	109	*19*
	2014	29.4	1680	135	*8.5*	*316*	*30*	12.0	1232	*86*	*9.0*	*131*	*19*
	Ave.	***23.4***	***2080***	***152***	***9***	***493***	***46***	***7***	***1425***	***87***	***8***	***162***	***18***
Skandia	2009	30.4	1753	175	12.7	*413*	59	7.6	*1224*	92	10.1	116	24
	2010	17.4	2295	208	5.9	651	75	5.7	1412	92	5.8	232	41
	2011	20.4	2126	182	7.1	456	55	4.4	1438	92	8.9	232	35
	2012	17.1	2044	186	3.2	*611*	63	7.4	1309	92	6.5	124	31
	2013	18.1	1600	134	4.4	247	25	*9.5*	1185	87	4.2	*168*	22
	2014	16.7	1617	152	5.1	330	35	*2.7*	*1139*	*91*	*8.9*	*148*	*26*
	2015	12.9	1987	121	*NA*	*NA*	*NA*	*3.7*	*1816*	*90*	*9.2*	*171*	*31*
	Ave.	***20.7***	***1964***	***177***	***6***	***451***	***52***	***6***	***1360***	***91***	***8***	***170***	***30***

TABLE 4: Yield Data Availability From Willow Trials in Michigan

Trial Type	*Location*	*Year Established*	*Coppice*	*1st Rotation*	*2nd Rotation*	*3rd Rotation*	*3rd Rotation*
Yield Trials							
12-varitey Yield Trial (1)	Escanaba	2002	-	2004	2007	2010	2013
	Lansing	2002	-	2006	-	-	-
33-variety Yield Trial (2)	Escanaba	2008	2008	2011	2014		
	Skandia, Brimley	2009	2009	2012	2015		
	Onaway, Lake City	2010	2010	2013	**2016**		
	Albion	2011	2011	2014	**2017**		
24-variety Yield Trial	Escanaba	2012	-	2015	**2018**		
Production Blocks (3)							
Tully Champion	Escanaba	2010	-	2013	**2016**		
Millbrook	Escanaba	2012	-	2015	**2018**		

NOTES:

(1) This early willow variety yield trial contains 12 varieties of willow and 2 varieties (NM6 & NM5) of hybrid poplars for comparison. Cuttings were planted at a density of 7,260 stems per acre.

(2) These 6 plantations are distributed throughout Michigan. 10 varieties are common among all 6 plantations and there are a total of 33 varieties across the entire network. Cuttings were planted at a density of 5,808 stems per acre.

(3) These production blocks are 3 acres each, planted using the standard SUNY 2-row spacing. Cuttings were planted at a density of 5,808 stems per acre.

Table 5: Biomass accumulation of the top two willow and top two poplar varieties in a yield trial in Escanaba, Michigan. Mean Annual Increment during each 3-year rotation and total accumulated biomass during the 12 years of the trial are presented.

Plantation Age (harvests occur every 3 years)	*MAI (dry Mg•ha^{-1} •yr^{-1})*		*Accumulating Biomass (dry Mg•ha^{-1})*	
	Willow	*Poplar*	*Willow*	*Poplar*
3	3.45	8.30	10.36	24.89
6	5.56	7.67	27.04	47.89
9	9.82	8.59	56.50	73.65
12	9.04	5.22	83.61	89.33
TOTAL	**6.97**	**7.44**		

Note: Multiply numbers in table by 0.446 to obtain yields in dry tons per acre

Figure 2. Projected Biomass Accumulation of the Top 2 Willow and Poplar Varieties in a 12-year-old Yield Trial in Escanaba, Michigan

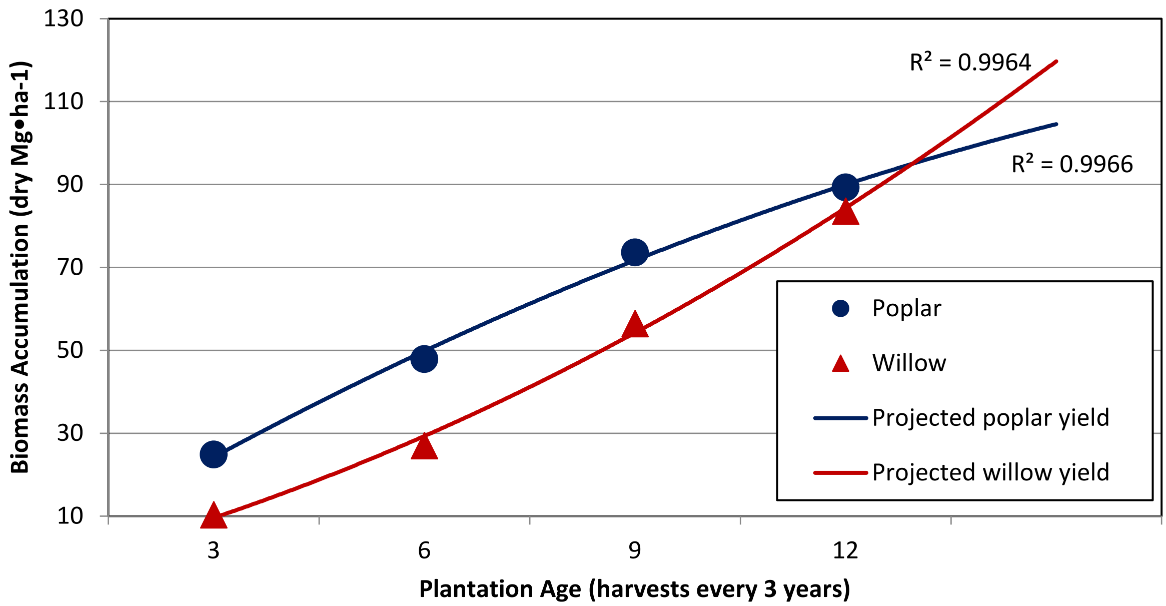

Table 6: Planting and Harvest Dates of Willow Yield Trials in Michigan

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.

Table 7: 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.

Table 8: 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*		*2nd Roation Data*			*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%	Salix miyabeana	
SX67		81%	100%			91%	Salix miyabeana	
Millbrook	91%	100%	93%	63%	73%	84%	Salix purpurea x miyabeana	77%
Oneida	74%	37%	91%	98%	70%	74%	Salix purpurea x miyabeana	
Oneonta	100%			91%	58%	83%	Salix purpurea x miyabeana	
Saratoga		42%	89%			66%	Salix purpurea x miyabeana	
Clone_L			81%			81%	Salix viminalis x miyabeana	73%
Fabius	89%	31%	87%	40%	83%	66%	Salix viminalis x miyabeana	
Otisco	80%		85%	74%	81%	80%	Salix viminalis x miyabeana	
Owasco	65%		75%	80%	58%	70%	Salix viminalis x miyabeana	
Taberg			76%			76%	Salix viminalis x miyabeana	
Truxton	75%	77%	76%	83%	52%	73%	Salix viminalis x miyabeana	
Tully Champion		88%	82%	76%	100%	87%	Salix viminalis x miyabeana	
Verona			58%	51%	58%	56%	Salix viminalis x miyabeana	
Canastota	98%		74%	76%	67%	79%	Salix sachalinensis x miyabeana	71%
Cicero	74%		61%			68%	Salix sachalinensis x miyabeana	
Marcy	86%		78%	69%	68%	75%	Salix sachalinensis x miyabeana	
Sherburne	64%	54%	62%	69%	57%	61%	Salix sachalinensis x miyabeana	
SV1	54%	46%	92%	55%	74%	64%	Salix dasyclados	64%
Allegany	61%	37%	64%	62%	58%	56%	Salix purpurea	62%
Boonville	78%	63%				71%	Salix purpurea	
FC185			85%	65%	44%	65%	Salix purpurea	
Fish Creek	80%	25%	98%	67%	41%	62%	Salix purpurea	
Onondaga			62%	69%	59%	63%	Salix purpurea	
Wolcott	55%	23%	78%			52%	Salix purpurea	
Clone_A			24%			24%	Salix eriocephala	26%
Clone_K		19%				19%	Salix eriocephala	
S25		21%	14%		18%	18%	Salix eriocephala	
S365		44%				44%	Salix eriocephala	
Preble	89%					89%	Salix viminalis x (S. sachalinensis x S. miyabeana)	87%
Clone_C	92%	77%				85%	Salix viminalis x (S. sachalinensis x S. miyabeana)	
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 9: 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 Compared to Skandia Cohort	***100%***		***73%***		***82%***		***87%***	
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 Compared to Brimley Cohort	***80%***		***100%***		***79%***		***98%***	
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 Compared to Escanaba Cohort	***89%***		***91%***		***100%***		***93%***	

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 substitued for comparison.

Table 10: Three-year biomass growth comparison of willow varieties in two yield trials in Escanaba, MI. Actual and relative yields of all varieties in the 2012 test are listed and the actual and relative yields of varieties common to the 2008 trial are included.

Variety Name	*2012 Yield Trial 1st rotation total yield*		*2008 Yield Trial 1st rotation total yield*	
	(dry t/a)	*Proportion of best variety*	*(dry t/a)*	*Proportion of best variety*
Saratoga	16.6	100%	10.7	78%
05X-291-049	16.4	99%		
Preble	16.2	98%		
01X-271-009	15.6	94%		
05X-281-068	15.4	93%		
Millbrook	15.3	92%	12.8	93%
05X-281-043	15.2	92%		
Canastota	14.9	90%	9.5	69%
SX61	14.6	88%	9.0	66%
Long Ashton	14.2	86%		
05X-291-050	13.7	83%		
Tully Champion	13.2	80%	13.5	99%
Fabius	12.9	78%	11.7	85%
Otisco	12.7	77%	12.7	93%
02X-326-015	12.3	74%		
02X-326-010	12.0	72%		
94006	11.7	70%		
Sheridan	11.7	70%		
Fish Creek	11.1	67%	12.8	93%
01X-265-019	10.4	63%		
Dimitrios	6.8	41%		
India	5.5	33%		
Klara	4.8	29%		
Stina	2.0	12%		