Planting density effects on biomass growth of hybrid poplar clones in Michigan: *A sixth-year update*.

Raymond O Miller
Bradford A. Bender
Michigan State University

MICHIGAN STATE UNIVERSITY

Stand Development Fundamentals

- Crop biomass per unit area increases without mortality until canopy closure, regardless of density. Stand development after canopy closure includes mortality. (Yoda, et. Al.; 1963)
- Crop biomass accumulation after canopy closure is differentially distributed among the surviving stems.

This is the biological underpinning of thinning theory.

Distribution of Biomass Among Stems

After canopy closure…

- Spacing/Density effects *individual tree* parameters (e.g. DBH, Ht, and volume)
- Spacing/Density has little effect on *stand* parameters (e.g. Basal Area (BA) and Biomass)
- The rate of biomass accumulation in the stand initially increases but eventually slows.

(Johnson; 2008, McAlpine, et. al.; 1966)

Variables to Consider

- Crop Factors
  - Genetics, pest resistance, resource use efficiency, biomass partitioning above and below ground.
- Site Factors
  - Soil fertility, sunlight, moisture availability, growing season length & temperatures.
- Management Factors
  - Competition control, phytophagy, fertilization, irrigation, rotation length, planting density.

So What?

- Plant enough stems so that they occupy the site and convert site resources into crop biomass quickly.
- Don't plant too many, because then you just waste money on unnecessary trees.
- Wait to harvest until biomass production has been optimized but not so long that the biomass produced does not pay for the initial investment plus interest.

Previous Work With Poplar

- Planting densities below 1,100 s/h are optimal for producing solid wood products like pulpwood and sawtimber but not biomass.
- Biomass production on "short rotations" was roughly equivalent over densities ranging from 3,000 to 40,000 s/h.
- Here we tested planting densities between these two limits.

Experimental Design

- Randomized block design with four blocks
- Seven poplar taxa
  - P. deltoides (D105)
  - P. xcanadensis (DN5, DN34, NE222, & I4551)
  - P. nigra X P. maximowiczii (NM2 & NM6)
- Three densities
  - 1,900, 2,200, & 2,700 stools/hectare
- 0.04-ha "main plots" (1/10th acre)
  - 2.44m between rows
  - Variable spacing within rows (2.13, 1.83, & 1.52m)
  - Outside 2 trees excluded from "measurement plot"
- Target rotation age: 8 years

Plantation Layout

U08aj-2008 NRRI hybrid poplar clonal trial 6-blocks, 56 clones 1-tree plots, 8' x 5' spacing						78 D105
71 DN34	72 NE222	73 DN5	74 NM6	75 DN5	76 DN34	77 D105
70 NE222	69 NM6	68 I4551	67 I4551	66 I4551	65 D105	64 DN34
57 I4551	58 DN34	59 NM6	60 NE222	61 DN5	62 NM6	63 NE222
56 D105	55 D105	54 DN34	53 I4551	52 NE222	51 D105	50 NE222
43 NM6	44 DN34	45 DN5	46 DN5	47 I4551	48 NM6	49 DN5
42 I4551	41 NM6	40 NE222	39 NE222	38 I4551	37 DN5	36 NM2
29 D105	30 NM6	31 NM2	32 NM2	33 DN5	34 DN34	35 DN34
28 D105	27 I4551	26 D105	25 DN5	24 NM6	23 DN34	22 NE222
15 DN34	16 NE222	17 I4551	18 NM6	19 NM2	20 DN5	21 D105
14 NM6	13 NM2	12 DN34	11 I4551	10 DN5	9 NE222	8 I4551
1 NM2	2 DN34	3 NM6	4 DN5	5 D105	6 D105	7 NE222

Trial Size:
3.6 ha
Plot Size:
0.04 ha
(1/10 acre)

Map of Inner 32 Trees Within Plot (8' X 5' spacing)

Plot of 96 = 12/row * 8 rows, 64'x60' , 1089 Trees Per Acre

•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	1	16	17	32	•	•
•	•	2	15	18	31	•	•
•	•	3	14	19	30	•	•
•	•	4	13	20	29	•	•
•	•	5	12	21	28	•	•
•	•	6	11	22	27	•	•
•	•	7	10	23	26	•	•
•	•	8	9	24	25	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•

Map of Inner 28 Trees Within Plot (8' X 6' spacing)

Plot of 88 = 11/row * 8 rows, 64'x66' , 907 Trees Per Acre

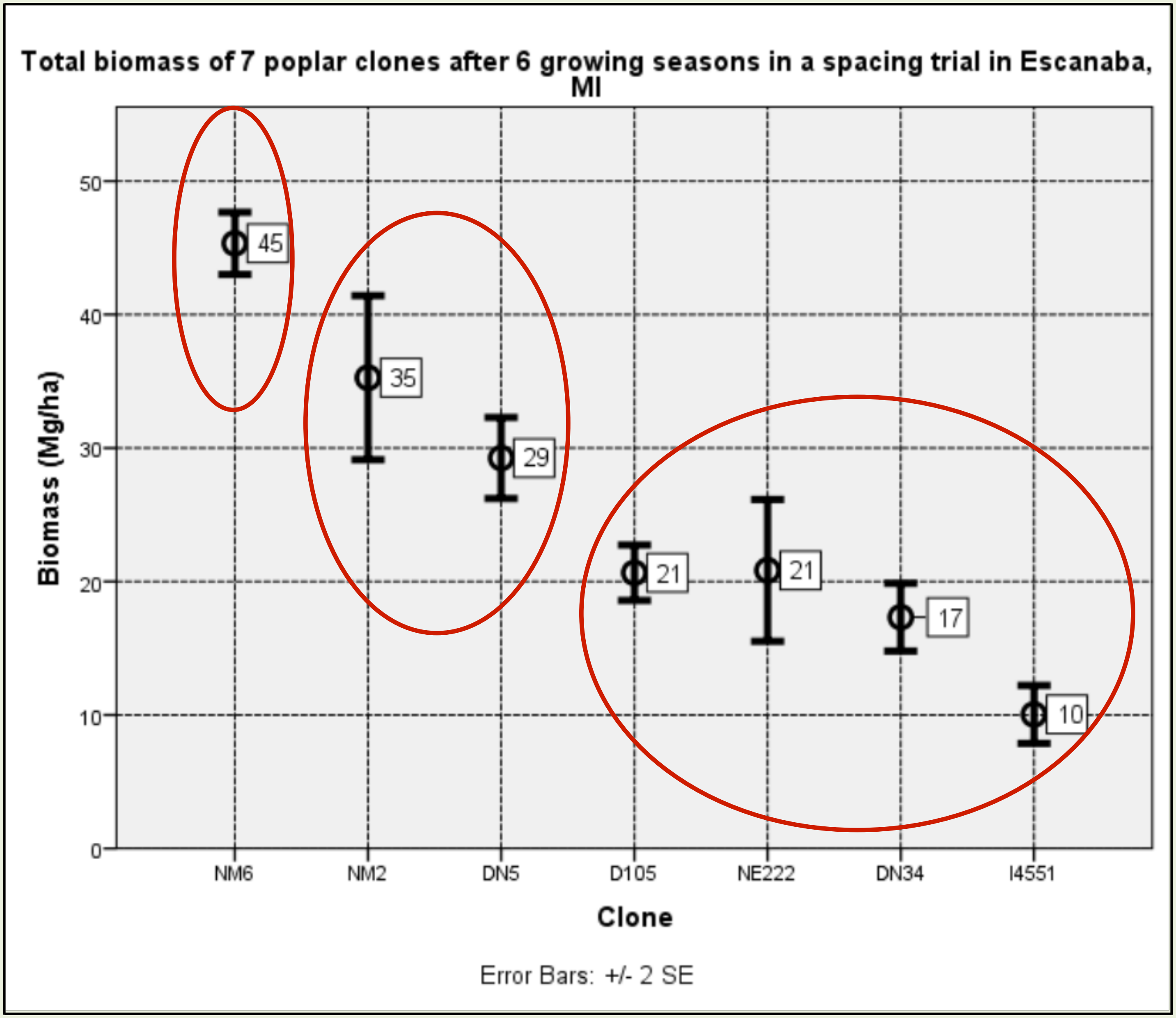
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	1	14	15	28	•	•
•	•	2	13	16	27	•	•
•	•	3	12	17	26	•	•
•	•	4	11	18	25	•	•
•	•	5	10	19	24	•	•
•	•	6	9	20	23	•	•
•	•	7	8	21	22	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•

Map of Inner 24 Trees Within Plot (8' X 7' spacing)

Plot of 80 = 10/row * 8 rows, 64'x70' , 777 Trees Per Acre

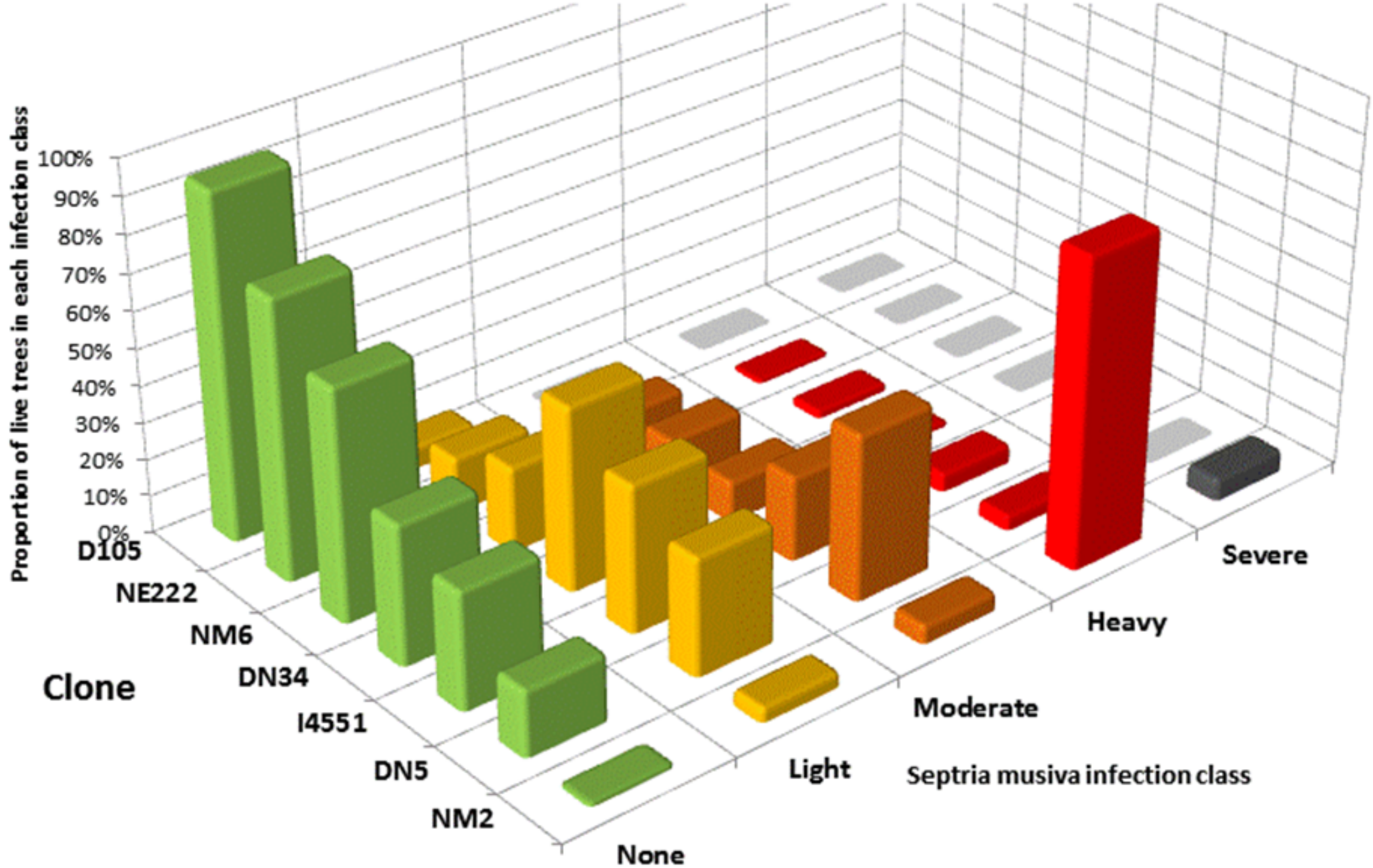
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•
•	•	1	12	13	24	•	•
•	•	2	11	14	23	•	•
•	•	3	10	15	22	•	•
•	•	4	9	16	21	•	•
•	•	5	8	17	20	•	•
•	•	6	7	18	19	•	•
•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•

The Life of a Spacing Trial



MICHIGAN STATE UNIVERSITY

Figure 3: Severity of *Septoria musiva* infection in 7 poplar clones after 6 growing seasons in Escanaba, MI



MICHIGAN STATE UNIVERSITY

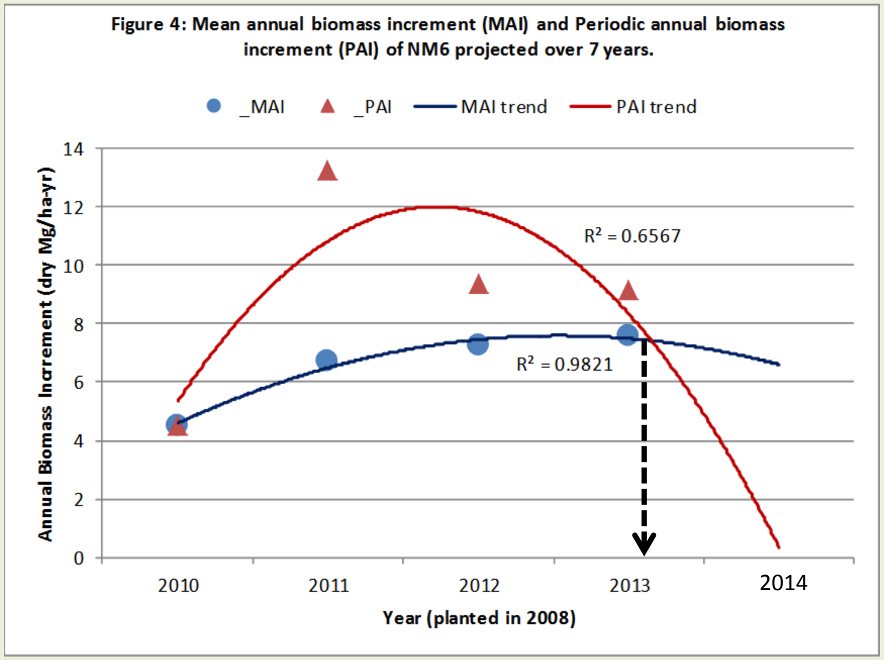


Figure 4: Mean annual biomass increment (MAI) and Periodic annual biomass increment (PAI) of NM6 projected over 7 years.
_MAI
_PAI
MAI trend
PAI trend
Annual Biomass Increment (dry Mg/ha-yr)
14
12
10
8
6
4
2
0
R² = 0.6567
R² = 0.9821
2010
2011
2012
2013
2014
Year (planted in 2008)

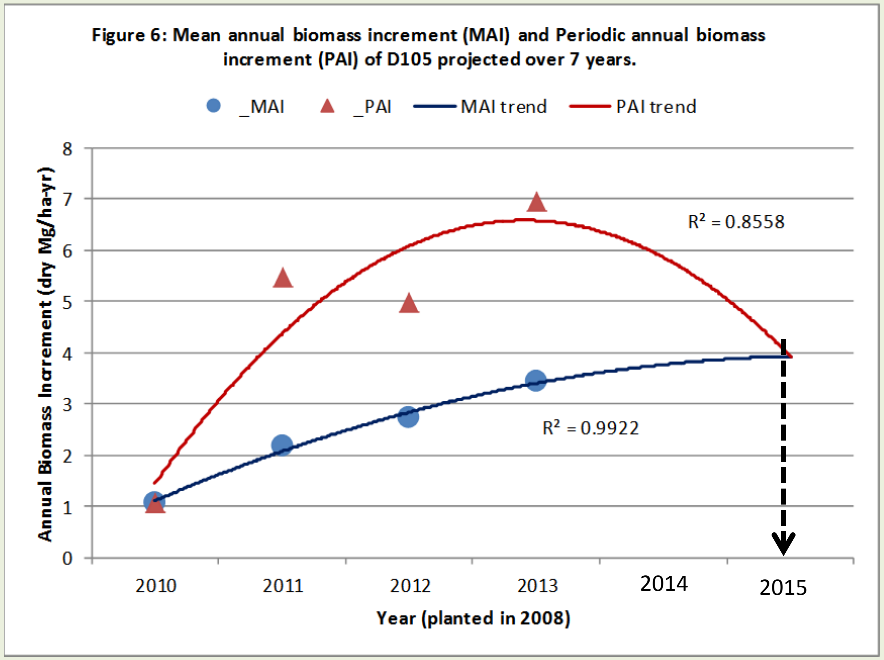


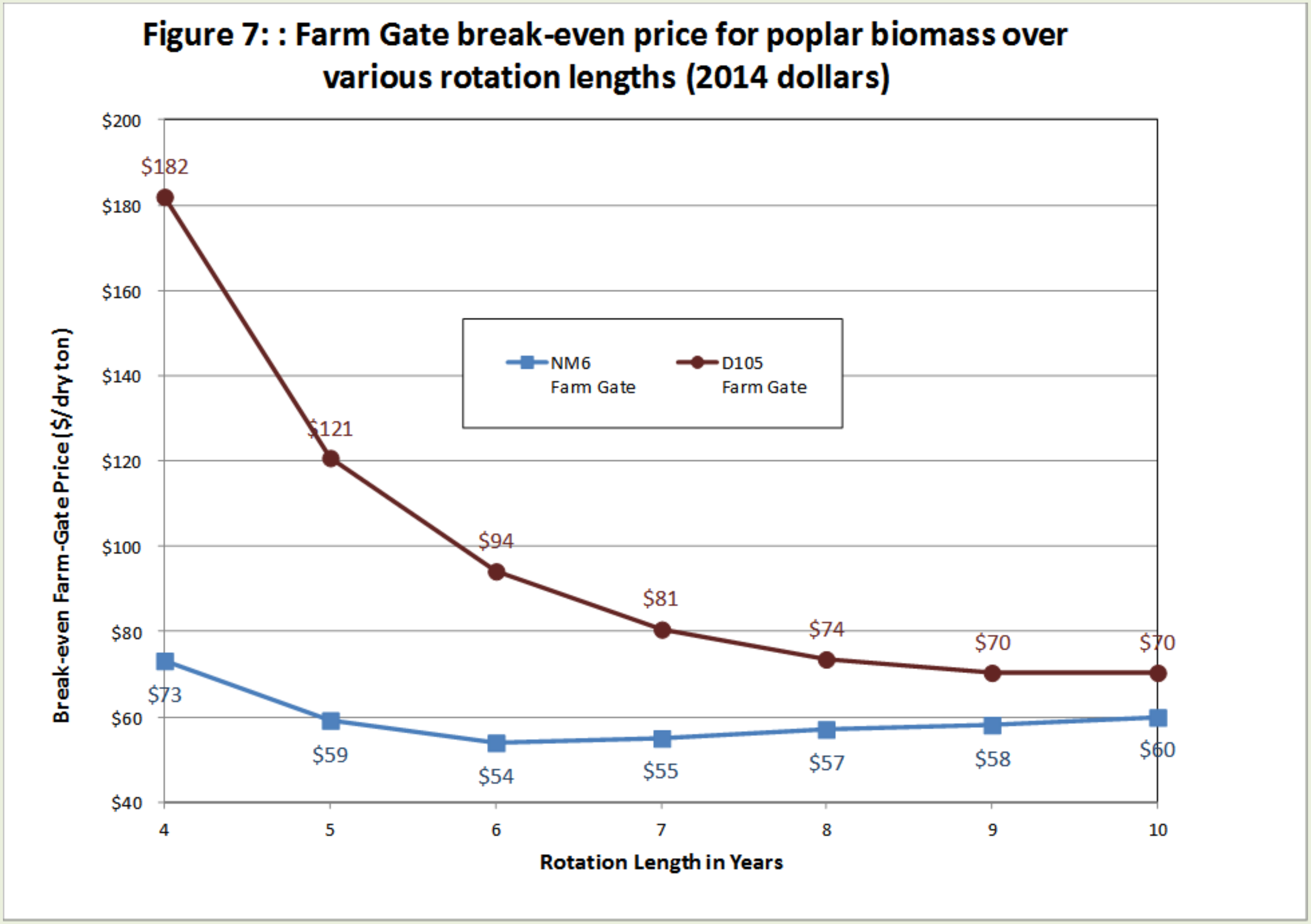
Figure 6: Mean annual biomass increment (MAI) and Periodic annual biomass increment (PAI) of D105 projected over 7 years.
_MAI
_PAI
MAI trend
PAI trend
Annual Biomass Increment (dry Mg/ha-yr)
8
7
6
5
4
3
2
1
0
R² = 0.8558
R² = 0.9922
2010
2011
2012
2013
2014
2015
Year (planted in 2008)

Figure 1: Break-even Analysis of Poplar Production for NM6 hybrid poplar

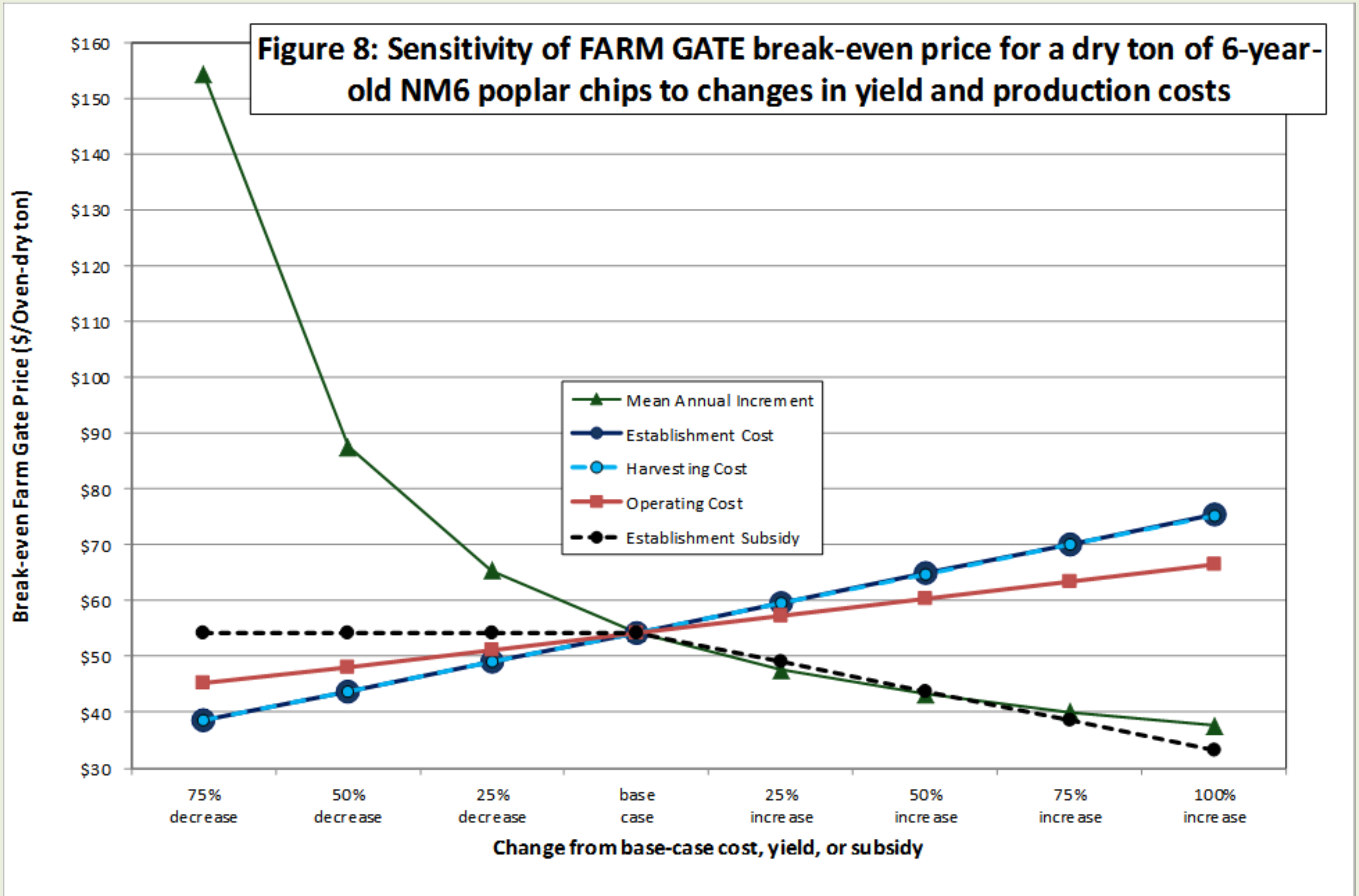
Discount rate: *5%*

Activity	Price (2014 dollars)	Unit	*Calendar Year within project*										
			2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
			site preparation	plant	Tend	Idle	1st possible harvest	Subsequent years in which harvesting may occur					
Number of Interest Periods or Growing Seasons			0	1	2	3	4	5	6	7	8	9	10
Establishment Costs													
Herbicide Chemical	$ 7.00	$/acre	$ 7.00										
Herbicide Application	$ 6.00	$/acre	$ 6.00										
Tilliage	$ 20.00	$/acre	$ 20.00	$ 42.00									
Plantation Layout	$ 15.00	$/acre		$ 15.75									
Herbicide Chemical	$ 75.00	$/acre		$ 78.75	$ 82.69								
Herbicide Application	$ 6.00	$/acre		$ 6.30	$ 6.62								
Tilliage	$ 20.00	$/acre		$ 21.00	$ 22.05								
Planting Stock	$ 0.12	$/cutting		$ 97.90									
Planting Labor	$ 0.05	$/cutting		$ 40.79									
Sub-Total Establishment Costs		$/acre	$ 33.00	$ 302.49	$ 111.35								
Adjusted Establishment Cost for sensitivity	100%	% of base cost	$ 33.00	$ 302.49	$ 111.35								
Establishment subsidy	0%	% of full cost/a	$ -	$ -	$ -								
Recurring Operating Costs													
Land Rent	$ 25.00	$/acre	$ 25.00	$ 26.25	$ 27.56	$ 28.94	$ 30.39	$ 31.91	$ 33.50	$ 35.18	$ 36.94	$ 38.78	$ 40.72
Plantation Management	$ 10.00	$/acre	$ 10.00	$ 10.50	$ 11.03	$ 11.58	$ 12.16	$ 12.76	$ 13.40	$ 14.07	$ 14.77	$ 15.51	$ 16.29
COST SUMMARY													
Annual Expenses		$/acre	$ 68.00	$ 339.24	$ 149.94	$ 40.52	$ 42.54	$ 44.67	$ 46.90	$ 49.25	$ 51.71	$ 54.30	$ 57.01
Accumulating Future Value of Costs		$/acre	$ 68.00	$ 410.64	$ 581.12	$ 650.69	$ 725.77	$ 806.72	$ 893.96	$ 987.91	$ 1,089.02	$ 1,197.77	$ 1,314.66
Accumulating Biomass													
Biomass MAI (from spacing trial)		dry Mg/ha-yr					6.49	7.45	7.49	6.60	5.80	5.20	4.70
Biomass MAI (converted to english units)		dry tons/acre-yr					2.89	3.32	3.34	2.94	2.59	2.32	2.10
Adjusted Yield (for sensitivity analysis)	0%	% incr. or decr.					2.89	3.32	3.34	2.94	2.59	2.32	2.10
Accumulated Biomass		dry tons/acre					11.57	16.62	20.04	20.59	20.69	20.87	20.96
Harvesting Costs													
Harvesting Cost per dry ton	$ 21.00	$/dry ton					$ 25.53	$ 26.80	$ 28.14	$ 29.55	$ 31.03	$ 32.58	$ 34.21
Harvesting Cost per Acre		$/dry acre					$ 295.40	$ 445.45	$ 563.98	$ 608.40	$ 642.08	$ 679.99	$ 717.04
TOTAL future value FARM GATE cost		$/dry acre					$ 1,021.17	$ 1,252.18	$ 1,457.95	$ 1,596.32	$ 1,731.09	$ 1,877.76	$ 2,031.71
FARM GATE BREAK-EVEN Price (Present Value)		**$/dry ton**					**$ 72.59**	**$ 59.03**	**$ 54.29**	**$ 55.10**	**$ 56.62**	**$ 57.99**	**$ 59.50**
Hauling cost for biomass to Mill	$ 15.00	$/dry acre					$ 211.00	$ 318.18	$ 402.84	$ 434.57	$ 458.63	$ 485.71	$ 512.17
TOTAL future value MILL GATE cost		$/dry acre					$ 1,232.17	$ 1,570.36	$ 1,860.79	$ 2,030.89	$ 2,189.72	$ 2,363.47	$ 2,543.88
MILL GATE BREAK-EVEN Price (Present Value)		**$/dry ton**					**$ 87.59**	**$ 74.03**	**$ 69.29**	**$ 70.10**	**$ 71.62**	**$ 72.99**	**$ 74.50**

MICHIGAN STATE UNIVERSITY



MICHIGAN STATE UNIVERSITY



MICHIGAN STATE UNIVERSITY

Conclusion

1. Planting density had no impact on biomass productivity but choice of clone did. NM6 was the best (45 dry Mg·ha^{-1}) while D105 was among the poorest (21 dry Mg·ha$^{-1)}$ after six years. While choosing the proper clone can significantly improve SRE Plantation profitability, there is no advantage to increasing planting density above 1,900 stools·ha^{-1}.

Conclusion

2. Disease is beginning to reduce growth and increase mortality of certain clones. NM2 is heavily infected by Septoria musiva. Stems are breaking and mortality is increasing. Only the slowest growing clones are lightly infected. Breeding clones that combining fast growth with disease resistance should be the highest priority of all research efforts.

MICHIGAN STATE UNIVERSITY

Conclusion

3. Biological rotation for the faster growing clones (like NM6) was reached after six years and appears to be coming in year eight for the slower growing clones (like D105). The lowest break-even price for NM6 was $54/ dry ton after six years and appears to be $70/ ton for D105 after nine years.

MICHIGAN STATE UNIVERSITY

Conclusion

4. Break even prices are sensitive to establishment and harvesting costs. Increases in yield drive break even prices significantly down in much the same was as plantation establishment subsidies do. Yield losses are catastrophic to the finances of SRE Plantation systems. Research and education to help growers avoid management errors together with simple good luck in avoiding bad weather and crop predation are absolutely critical to the financial success of SRE Plantations.

THANK YOU…

rmiller@msu.edu

Acknowledgement:
"This material is based upon work supported by the Department of Energy under award number DE-EE-0000280."