COMMON SHORT ROTATION POPLAR GROWTH PATTERNS OBSERVED IN TEN TRIALS OVER 18 YEARS IN MICHIGAN, USA

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ABSTRACT

Hybrid poplars are prime fiber and biomass producing crops around the world. Growth varies widely in response to climate, edaphic factors, varietal genetics, cultural practices, pest pressures, and the interactions among all these things. Testing is expensive and so is often done over short time intervals, at single sites, using a limited number of varieties, and done only once, which means that conclusions must be qualified with many caveats. Because of poplar's tremendous variability and the practical limitations that constrain research, reported responses from individual poplar trials are often not precisely repeatable in large, widespread commercial operations.

Michigan State University began a series of hybrid poplar trials in 1998. These included herbicide trials, fertilizer trials, variety trials, yield trials, and spacing trials. Some trials were conducted at the Forest Biomass Innovation Center in Escanaba, Michigan, USA but others were replicated throughout the state. Here we attempt to distill the observations made in these individual trials over the last 18 years into a cohesive summary of biomass yield projections, growth patterns and rotation length projections, and varietal responses to stress and cultural treatments. We also suggest what research remains to be done to improve the chances of commercial deployment of the production system being developed here.

INTRODUCTION

Demand for renewable carbon to produce energy, fuels, and materials is increasing. Biomass is the only renewable source of carbon, and identifying crops that can thrive on idle or retired agricultural land is necessary to avoid competition with already strained food and fiber production. Crops that can be managed successfully with minimal inputs (e.g. water, chemicals, and energy) will be the most desirable. In many parts of the world, hybrids of various members of the genus *Populus* promise to be that crop. There are many varieties to choose from but most tend to perform best only under specific conditions, so careful, local testing and selection is necessary.

Poplar biomass plantations require a type of forest management (silviculture) that is generally unfamiliar to both foresters and farmers alike. Traditional silviculture is optimized for the production of large trees on long cutting cycles (rotations). Although the underlying fundamentals are similar, this new silviculture must account for unfamiliar tree varieties, short rotations, new landowner expectations, and be optimized for the rapid production of biomass – a low-value forest product. Since the goal is to produce biomass quickly, regardless of individual tree size, this silviculture research focuses on the biology and finances of the first few years of stand development.

Successful poplar production absolutely depends on long-term field testing of varieties on sites close to where commercial plantings will be established. Testing of hybrid poplar varieties in the Lake State region dates back decades, but recent coordinated testing in Michigan, Wisconsin, Minnesota, and Iowa was organized under the auspices of the North Central *Populus* Research Consortium in the mid-1990s. This work has been carried forward more recently through the National Biomass Feedstock Partnership Program with funding from the US Department of Energy. A series of poplar herbicide trials, fertilizer trials, variety trials, yield trials, and spacing trials have been conducted throughout Michigan during this period. It is possible now to identify suitable varieties and define the silviculture systems needed by biomass growers in the Midwest.

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. What follows is an attempt to answer these three questions, drawing from almost two decades of hybrid poplar research and experience at Michigan State University's Forest Biomass Innovation Center.

What should I plant?

Mid-western poplar plantations are established using dormant hardwood cuttings (clones) of various hybrids of individuals from several poplar species (*e.g. Populus deltoides*, *P. nigra*, and *P. maximowiczii*). Development and testing of these hybrids began decades ago and has continued most recently with leadership from the Natural Resources Research Institute (NRRI) of the University of Minnesota and collaboration from Michigan State University and others.

Varieties: Hybrids of various species from sections *Tacamahaca* and *Aigeiros* of the genus *Populus* are commonly used around the world for a range of products and ecosystem services. In addition to their other favorable characteristics, clones of these commercial hybrids are easily and economically propagated from dormant hardwood cuttings. Unfortunately, many of these commercial hybrid poplar varieties are susceptible to diseases that can render them unusable in some regions of North America. However, there are other poplar hybrids from section *Populus* (the white or gray poplars and aspens) that grow well and resist many of these disabling diseases but which are less easily propagated, owing to their inability to develop roots from dormant hardwood cuttings. This makes them more difficult and expensive to manage in energy plantations. While most of the work done in the Midwest (and discussed here) has concentrated on the varieties that are easily propagated from dormant hardwood cuttings (Miller and Bender, 2016b), efforts continue to look for white poplar and aspen varieties with commercial potential (Miller *et. al.* 2014).

There can be a six-fold difference in yield among varieties so choosing appropriate genotypes for specific sites is critical. Poplar varieties exhibit strong genotype X environment interaction – meaning that there will never be a single "best" variety for universal use. Rather, elite varieties will only be identified through local testing. While not necessarily the best yielding varieties, several have been found to be good "*general performers*" across a network of trials in Michigan (*e.g.* the *P. nigra* X *maximowiczii* hybrids **NM6**, **NM5**, the *P. deltoides* X *maximowiczii* variety **DM114**, and the *P. deltoides* X *nigra* variety **DN2**). While general performers will work well on many sites, there will be times when they fail and other times when different varieties will outperform them.

Many poplar varieties are highly susceptible to insect, disease, and animal pests. When poplar plantations are first introduced to an area where they had previously been unknown, it may take one rotation for the pest populations to build to levels where they become problematic. Once present, these pests can be devastating. Two of the fastest growing varieties (NM5 and NM6) are highly susceptible to a debilitating stem canker disease (*Septoria musiva*). Resistance to this particular pest is rare among Midwestern poplar varieties. DN34 is an old variety that does appear to resist cankering, but it tends to be a mediocre grower and may never be able to produce enough biomass on short rotations to be commercially viable (Miller and Bender, 2016a). New varieties are being developed by the NRRI breeding program. Some of these have similar yields to these older varieties and promise to have better disease resistance (Miller, 2016c). Additional testing remains to be done to confirm this. Regardless of the variety, quality planting stock is a prerequisite to successful plantation establishment.

Planting Stock: Healthy, viable, and abundant planting stock will be needed if biomass plantations are to reach the potential predicted in the Billion Ton Study of the DOE. Commercial nurseries in the Midwest are not producing enough poplar cuttings to accommodate extensive field plantings. There are no sources of the new varieties and only one or two sources for the older varieties. This is due primarily to the lack of demand from potential growers which is, in turn, a function of poor markets for plantation-grown biomass in the region today.

This situation demonstrates a key barrier to realizing the potential of poplar production in the Midwest: *The feedstock supply chain takes time to establish*. Growers must become familiar with new silvicultural systems and overcome their natural reluctance to assume risks associated with new crops. It takes approximately two decades to develop, test, and identify a new elite poplar variety. At least another decade will pass before commercial nurseries produce enough planting stock and commercial growers plant, grow, and finally harvest this new crop. It should be clear that feedstock buyers cannot expect to simply turn this system on and off at will.

Yield: Growth of poplar varieties in numerous unfertilized and unirrigated tests in Michigan has varied widely. Roughly half of the variation was attributed to climatic and edaphic differences among planting sites. A quarter of the variation was due to genetic differences among the varieties, including the interactions between the varieties and the planting sites. The remaining quarter of the variation was due to tree-to-tree differences arising from cultural and unexplained factors. Mean annual increment of the NM6 standard variety was as much as 4.2 dry tons/acre-year under ideal conditions and as little as 0.6 dry tons/acre-year under the least favorable conditions. Average NM6 productivity in three trials conducted at the FBIC between 1998 and 2014 was 3.3 dry tons/acre-year after seven years (Figure 1). Considering the experience across the entire 6 site test network we established in Michigan, **it is reasonable to expect low-input commercial plantations to produce from 3.0 to 3.5 dry tons/acre-year over an 8 year rotation** if elite varieties are matched to appropriate sites and recommended silvicultural systems are employed. Obtaining this level of productivity requires experience, careful planning and management, and luck in avoiding catastrophes caused by frosts, droughts, and various pests.

How should I manage it?

Choose the right place to plant. All of our trials are un-fertilized and un-irrigated, but they have been placed on sites with substantially different fertility and moisture regimes so some general conclusions are possible. Poplar productivity seems to be best on sites with average moisture holding capacity and with pH between 6 and 7. Productivity tracked well with the number of growing degree days available on the sites and was exceptionally poor when there were fewer than 2,000 growing degree days available (Miller and Bender, 2016b). Site fertility and moisture can be altered artificially through fertilization, drainage, or irrigation. These practices will undoubtedly increase yields, but we have yet to study the effects of this on system energy and carbon balances or on system finances.

Plan for spatial and annual climatic variation. Annual climatic anomalies can produce impressive but unpredictable differences from one growing season to the next. For example, temperature and moisture conditions were ideal during the 2010 growing season in Escanaba. This caused trees in one three-year-old study to double in size that year. However, an adjacent two-year-old study did not respond in the same way. These younger trees were apparently not physiologically ready to take advantage of the conditions that year.

Catastrophic events are similarly unpredictable. A drought in 2012 in the southern part of Michigan caused growth to nearly stop at one site and resulted in the death of young plantations elsewhere in the network. At another northern site, a killing frost suddenly occurred one fall night following a prolonged period of warm weather. The one-year-old trees had been growing vigorously in the warm weather and were unprepared for the frost and so were severely damaged. The trees in the plantation never fully recovered. Growers need to be prepared for these uncontrollable random events; "*expect the unexpected*."

Prepare and maintain the site well. Among all pests, weeds deserve to be singled-out. The most common cultural cause of yield loss in energy plantations is weeds. Heavy weed growth coupled with dry conditions during the growing season can be devastating. 99% of the trees in a well weeded spruce plantation survived a severe first-season drought but only 24% of the trees survived in parts of the plantation with poor weed control (Miller, 1988). 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 (*mea culpa*) seasoned professionals.

Adequate site preparation, well in advance of plantation establishment, makes post planting weed control much easier. It is best to begin removing weeds the year prior to planting and continue with multiple chemical and mechanical treatments as needed. Past land use can determine the severity of weed competition after planting. Recently tilled agricultural fields tend to be less weedy than former pastures or meadows. Post-planting weed control during the first two growing seasons is vital to early crop establishment and development. Financial sensitivity analysis has revealed a strongly non-linear and negative impact of reduced yields on short rotation plantation profitability (Figure 2 from Miller, 2016b). Losses incurred due to early stress in these plantations cannot be overcome with subsequent management treatments. There is absolutely no substitute for giving trees a strong start in these plantations.

In the year PRIOR to planting, remove brush and mow existing vegetation early enough in the growing season to allow weeds and grasses to regrow. While still actively growing, spray this vegetation with a broad-spectrum, but non-persistent herbicide such as glyphosate[1] (2 pounds active ingredient per acre in enough water to adequately cover the weeds). Once the weeds are dead (approximately 2 weeks later) plow and cultivate the area to a minimum depth of 8 inches.

In the spring of the planting year, allow enough time to pass for any weed growth to emerge. Spray these weeds prior to planting with another application of a broad-spectrum, but non-persistent herbicide. Re-cultivate the field after this herbicide application has had time to kill the weeds. This can be done with a cultivator, discs, rototiller, or similar implement.

Plant healthy stock. Obtain 10” dormant hardwood cuttings for planting and keep refrigerated (frozen if possible) until the day of planting. Keep the cuttings moist and cool and out of direct sun and wind. Insert the cutting to their full length, either mechanically or by hand, into the well-worked soil (buds pointing up). Space the cuttings in a way to facilitate subsequent weed control and harvesting operations. A rectangular spacing producing a planting density of approximately 800 trees per acre is adequate (Miller and Bender, 2016a).

Planting density, variety growth habits, and target rotation age are strongly interrelated. One combination might maximize biomass yield in the short term but be financially unfavorable to the grower. Another combination might be inexpensive to establish but never produce significant quantities of biomass. Experience in Michigan suggests that better yielding poplar varieties (*e.g.* NM6, DM114, and DN2) reach financial rotation age in 6-8 years while slower growing varieties like NE222 require 9 or more years when planted at a density of 778 trees per acre (Figure 3 & 4 from Miller and Bender, 2016a). Higher densities are more costly to establish and neither shorten rotation length nor increase final biomass yield. An advantage of lower density plantations is that individual trees grow larger and become useful for products, such as pulpwood, that might be more valuable than generic biomass.

Post-planting maintenance. Apply a pre-emergence herbicide immediately after planting being careful not to apply directly to any green growing parts of the trees. Pendimethalin[2] (3 quarts product/acre) mixed with imazaquin[3] (5.6 dry ounces product/acre) is effective and can be alternated in subsequent years with flumioxazin[4] (10 ounces of product/acre) to prevent the build-up of resistant weed populations (Miller and Bloese, 2002). Mowing and mechanical cultivation may be necessary later during the growing season and a re-application of both a pre- and post-emergence herbicide during the dormant season prior to the second growing season is recommended.

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[1] Roundup®
[2] Pendulum®
[3] Scepter®
[4] SureGuard®

It is common for grasses (C4 plants) to invade newly planted poplar stands and these can be difficult to eliminate through mechanical means. Herbicides like sethoxydim[5] and fluazifop[6] specifically target C4 plants and can be safely applied over actively growing poplar (Miller, 1999). This method of grass control is problematic in practice because these herbicides are only effective when applied at very particular physiological stages in the development of the grass plants. It is often operationally difficult to get the timing correct.

Diseases, insects, and browsing animals express selective preference for various taxa and varieties (Miller and Bender, 2016a). Browsing animals can be excluded during the early years of a plantation by fencing or by applying chemical repellents to the trees. Fencing is expensive but can be a permanent solution to the problem. Repellents must be reapplied after rainfall and so can also be expensive. This certainly has an impact on the finances of the production system but in some locations is the only way to ensure successful establishment of these plantations. In rare instances, insecticides might be used to reduce the impact of insect pests, but this is usually done only in the context of an Integrated Pest Management Program. The only defense against diseases is to find and plant poplar varieties that resist or co-exist well with the pathogens.

Harvesting and regeneration. Poplars grown for more than six years will be large enough to be harvested using conventional forestry equipment. Generally speaking, harvesting represents approximately one third of the total cost of the poplar production system (approximately $22/dry ton according to one of our recent studies). Harvesting less often (lengthening the rotation) is one strategy to reduce overall costs. Poplar will produce numerous sprouts from cut stumps (and roots) following harvesting. If growers are satisfied with a second generation stand with many smaller stems, there is no need to incur the expense of replanting following a harvest. On the other hand, if the grower wishes to produce larger, single-stemmed trees again or if the grower wishes to switch to a newer, more productive or more pest resistant variety, it will be necessary to kill the sprouts of the original stand. A fallow year between harvest and replanting will be needed to kill emerging sprouts by spraying with glyphosate or a similar herbicide. The site can subsequently be prepared by spraying, cultivating, and planting into the area between the stumps of the previous stand.

Will I make money if I do that?

Varieties that have early rapid growth produce biomass at the least cost and do so more quickly than slow-growing clones. Using a model we developed for analyzing production costs (Miller, 2016b), NM6 (a rapid grower) provided the lowest break-even farm gate price ($54/ dry ton) of any variety after six growing seasons. The lowest break-even farm gate price for D105 (a very slow grower) was projected to be $70/dry ton after the ninth growing season (Figure 5 from Miller, 2016b).

Many rapidly growing varieties (like NM6) tended to be prone to disease. Consequently while costing less per ton to produce they will present growers with a higher risk of crop loss. Biomass from slower growing but more disease resistant clones like D105 or DN34 will have higher unit production costs but will present growers with a much lower risk of crop loss. Consequently,

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[5] Poast®

[6] Fusilade®

growers and investors must undertake an analysis of risk versus return when choosing among today's commercial poplar clones. Continued breeding and screening of new clones seeks to lower this risk, by imparting new clones with disease resistance while maintaining and even increasing growth (Miller, 2016c).

Cost sensitivity analysis. Break-even farm gate biomass prices are particularly sensitive to establishment and harvesting costs (Figure 2 from Miller, 2016b): A 25% change in either of these costs produces a 10% change in the break-even farm gate price of biomass. Recurring operating costs like annual land rent and management fees have a smaller impact: A 25% change in these costs produces a 6% change in break-even farm gate biomass prices. Establishment and harvesting costs can be reduced through conscientious application of best silvicultural practices and continued improvements informed by new research and equipment development. These costs can also be shifted using subsidies, or other similar mechanisms, to great effect. For example, the break-even cost of 6-year-old NM6 biomass can be reduced from approximately $54/dry ton to $33/dry ton if establishment costs are fully subsidized.

Increases in biomass yield have a similar impact on break-even prices as do increased establishment subsidies. A 25% increase in yield reduces break-even costs by 12% while a 25% establishment cost subsidy causes a similar reduction of 10%. Biomass yield can be increased by employing improved cultural practices and new genetic varieties. Both improvements rely on sustained and lengthy research and development projects. While these improvements are being developed, subsidies can provide growers and purchasers with similar cost benefits, thus incentivizing adoption of this otherwise risky production system. These subsidies can be reduced in the future as new systems and varieties are developed and deployed to cause biomass yield to increase.

A guaranteed way to lose money. Yield increases drive the cost of biomass down but yield losses result in a dramatic and non-linear increase in break-even biomass price. A 25% loss in yield increases break-even biomass price by 10%. A 50% yield loss increases break-even price by 61%. A 75% yield loss increases break-even price by a bank-breaking 184%. This happens because total system cost falls into two distinct categories; *fixed* and *variable*. Establishment and land rent costs are fixed and independent of yield. 61% of total costs in the base-case are *fixed*. Harvesting costs here are calculated based on the amount of biomass produced and so are *variable*. 39% of total costs in the base-case are variable. As biomass yield decreases, fixed costs become a greater and greater share of the total so the production cost of each remaining unit of biomass increases non-linearly.

Gains made from clever genetics, engineering, and management tricks to decrease break-even costs can be quickly eradicated by poor management or natural disasters that result in lost yield. The easiest thing a grower can do is to plant the wrong clone on the wrong site or to employ poor silvicultural practices; all of which result in poor yield. So, it takes a great effort to increase yield while it takes no effort at all to decrease yield. In other words, a clever grower can make money growing biomass but any fool can lose money. In fact, the less effort one applies the more money one can lose. Any plan to subsidize or otherwise support biomass growers should take this into account and ensure that growers have adequate technical support and that only the best available planting stock and production systems are employed. Only in this way can both the grower and society benefit from these programs.

When conditions are favorable, varieties are properly selected, and best management practices are followed, short rotation poplar plantations in Michigan can produce biomass for break-even farm gate prices of approximately $54/oven-dry short ton (Miller, 2016b). This price is slightly lower than the $60/dry short ton target set as the base case by the US Department of Energy in the 2016 Billion-ton Report (2016), and it is comparable to delivered pulpwood prices in the Upper Great Lakes States area. So, short rotation poplar biomass production in Michigan teeters on the cusp of profitability under average conditions.

But there are other reasons to plant poplar that have nothing to do with the farm gate price of the wood. These reasons include poplar's ability to provide *Landscape Services* in riparian zones, blighted urban spaces, brownfields, landfills, and wastewater treatment facilities. Locally produced products derived from locally grown poplar can revitalize and stabilize faltering rural communities producing *socio-economic benefits* (as opposed to simple financial benefits). Poplar plantations can provide a *hedge against future wood supply* uncertainty. Finally, substituting carbon from poplar plantations for fossil carbon from petroleum, coal, and natural gas can *reduce accumulation of greenhouse gasses* like CO_2 and methane in the atmosphere. These values are difficult to monetize and so they are ignored by today's markets. Society, however, can't afford to ignore them for much longer.

In today's climate of immediate payback and instant gratification, it is important to periodically look up from our balance sheets to see what is coming down the road toward us. In forestry there are two important axioms (which I have modified to fit the timeframe of poplar culture):

1. *The best time to plant poplar trees you wish to use now is 10 years ago.*
2. *The best time to start developing poplar varieties and production systems for the future is 25 years ago.*

We have recently made a start to satisfy these two axioms, but programs in Michigan and throughout the rest of the country are ending for lack of funding. But there is cheap oil and gas in the fractured shale, so never mind…….

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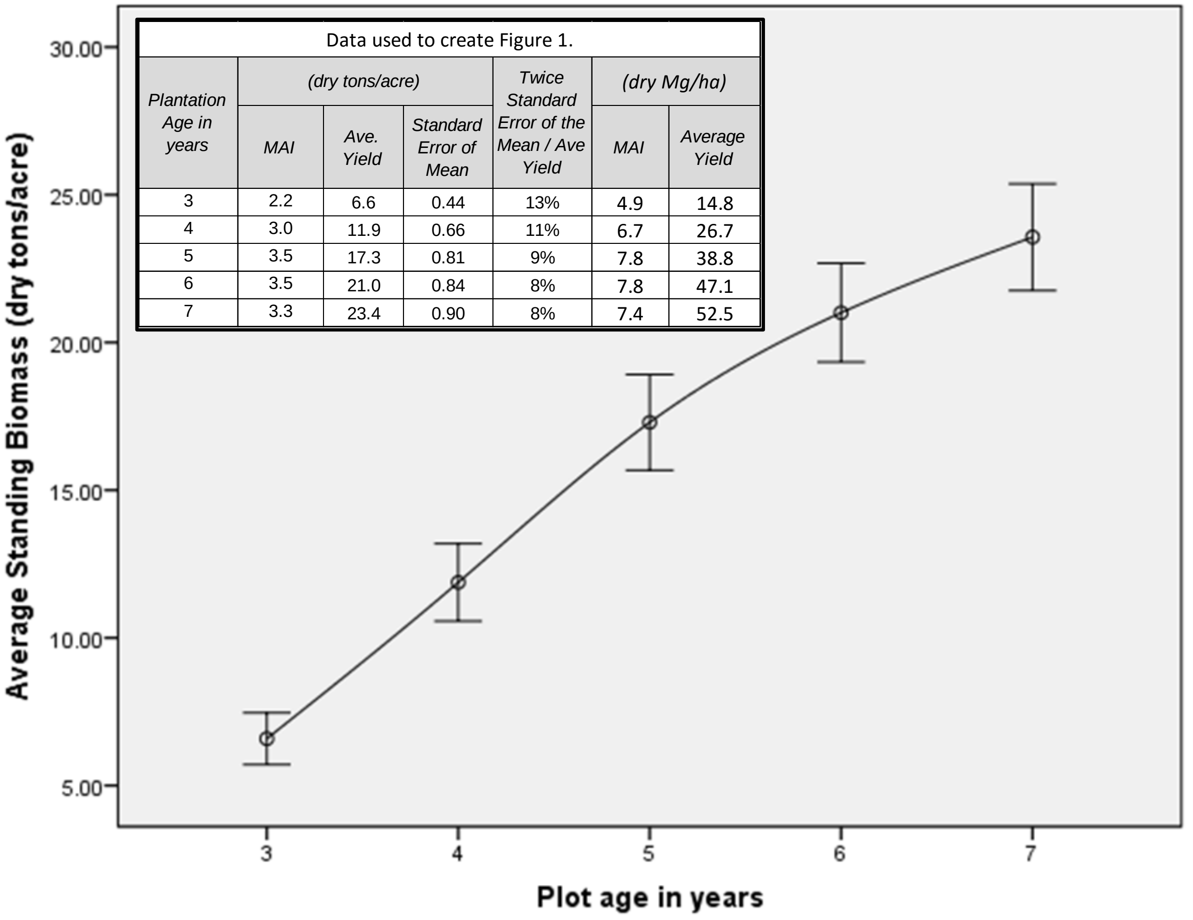
Figure 1: Average biomass production of NM6 poplar (the standard variety used in all Michigan poplar yield trials) in the 3rd through 7th growing seasons in Escanaba, MI, USA. Data was obtained from 29, tenth-acre sample plots that were part of three replicated trials established in 1998, 2008, and 2009. Standing tree biomass estimates were made from tree diameters measurements using an algorithm developed specifically for this region (Miller, 2016a). Circular points represent that average standing biomass (in dry tons per acre) and error bars represent twice the standard error of the mean. The curve through these points suggests that maximum mean annual increment (rotation age) may have been reached or will occur sometime in 8th year.



Data used to create Figure 1.

Plantation Age in years	*(dry tons/acre)*			*Twice Standard Error of the Mean / Ave Yield*	*(dry Mg/ha)*	
	MAI	*Ave. Yield*	*Standard Error of Mean*		*MAI*	*Average Yield*
3	2.2	6.6	0.44	13%	4.9	14.8
4	3.0	11.9	0.66	11%	6.7	26.7
5	3.5	17.3	0.81	9%	7.8	38.8
6	3.5	21.0	0.84	8%	7.8	47.1
7	3.3	23.4	0.90	8%	7.4	52.5

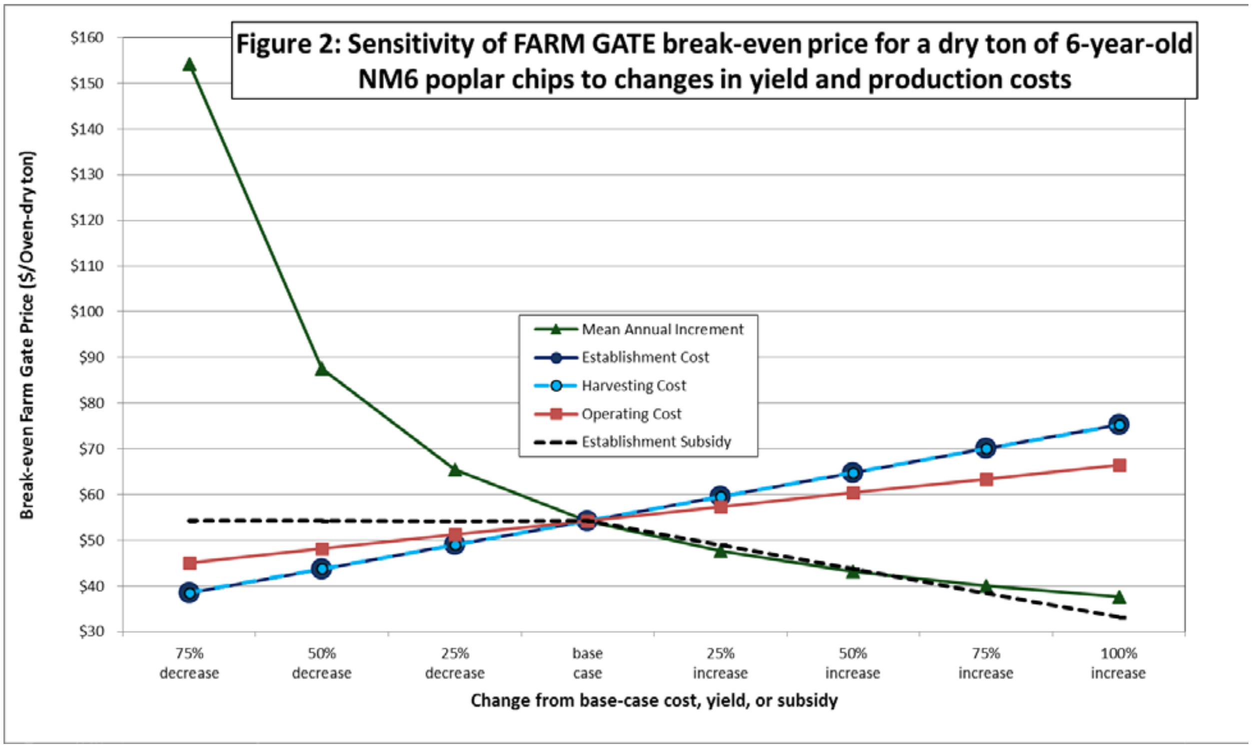


Figure 2: Sensitivity of FARM GATE break-even price for a dry ton of 6-year-old NM6 poplar chips to changes in yield and production costs

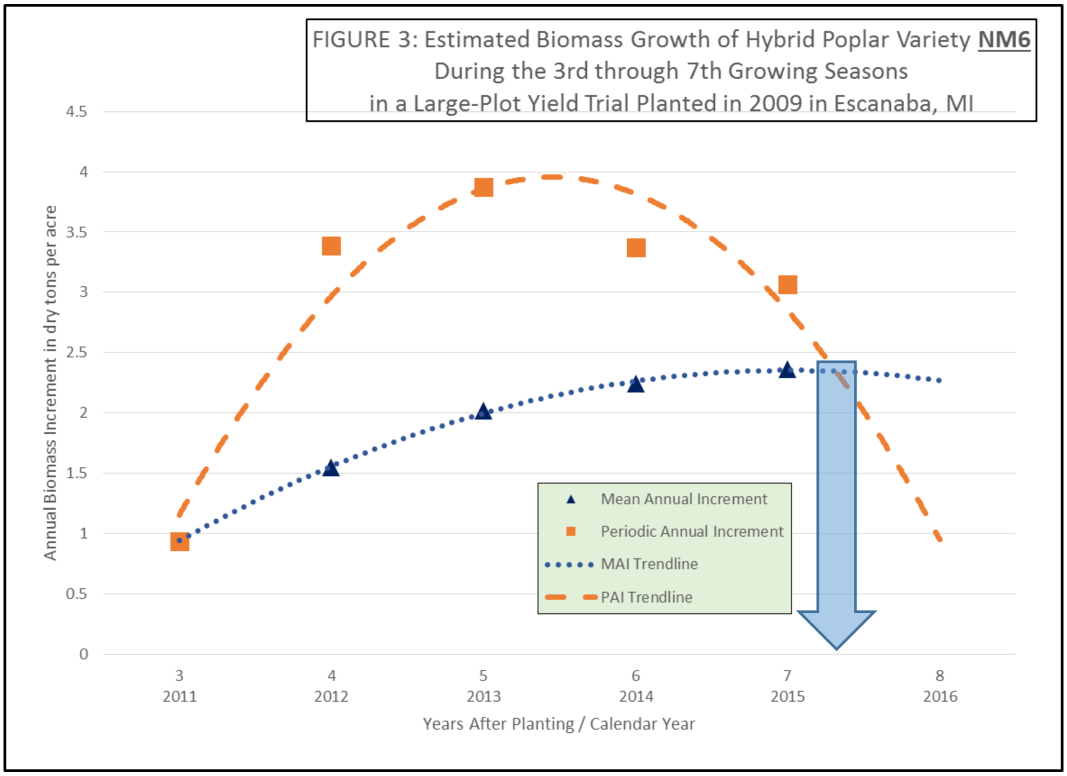


FIGURE 3: Estimated Biomass Growth of Hybrid Poplar Variety **NM6** During the 3rd through 7th Growing Seasons in a Large-Plot Yield Trial Planted in 2009 in Escanaba, MI

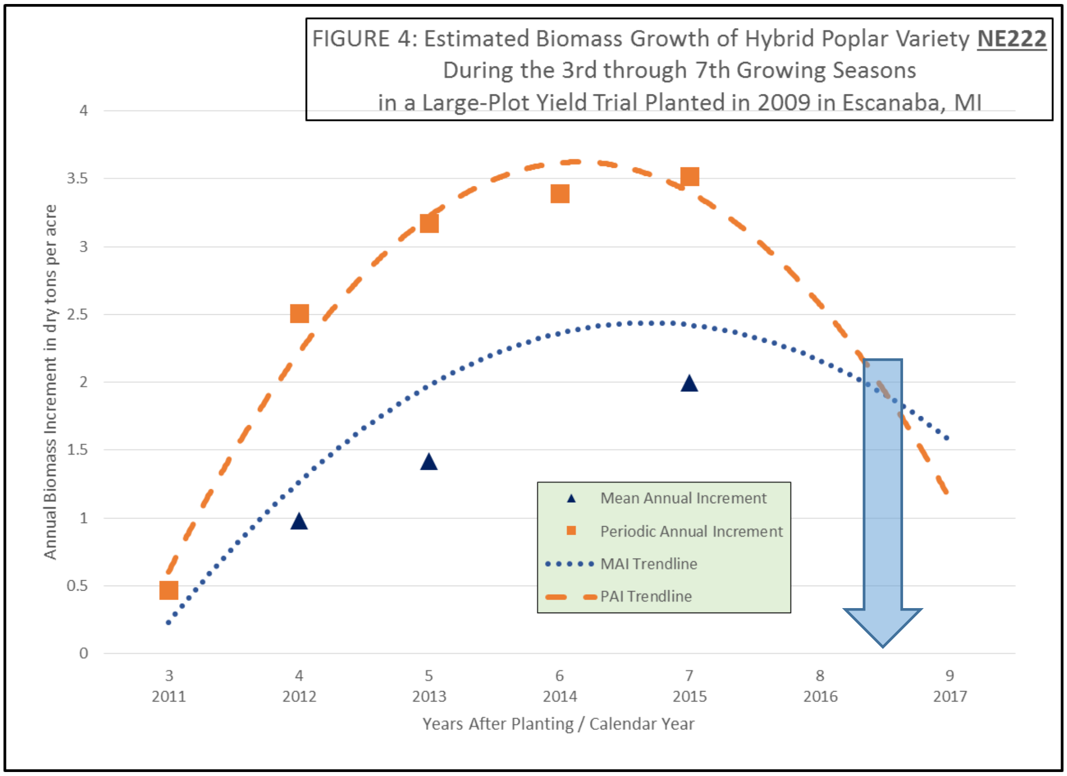


FIGURE 4: Estimated Biomass Growth of Hybrid Poplar Variety **NE222** During the 3rd through 7th Growing Seasons in a Large-Plot Yield Trial Planted in 2009 in Escanaba, MI

Figure 5: Farm Gate break-even price for poplar biomass over various rotation lengths (2014 dollars)