SHORT ROTATION FIBER FARMING IN MICHIGAN'S UPPER PENINSULA

Raymond O. Miller

ABSTRACT

The rapid production of wood fiber for energy, paper, and other products can be achieved using carefully selected varieties of fast-growing trees grown on short rotations in intensive cultural systems. Five poplar varieties and one European larch variety were grown for 11 years under short rotation intensive culture in Michigan's Upper Peninsula. A *Populus nigra* X *P. maximowiczii* hybrid (NM6) produced a mean annual biomass increment of 3.6 dry tons/acre-year or 11 cords/acre after 11 years. Three *P. deltoides* X *P. nigra* hybrids produced less biomass (2.4 to 2.0 dry tons/acre-year) but were far superior to both an aspen (*P. tremula* X *P. tremuloides*) and a larch (*Larix decidua*) during the 11 year duration of this test. Aspen and larch apparently require longer rotations to be commercially viable. At least 20% of all the poplar trees in this trial developed serious stem cankers. The most susceptible of these was DN5; half of the DN5 trees were cankered. Disease is perhaps the most serious impediment to the commercialization of these poplar varieties in the Lake States. Wood ash from a nearby paper mill was applied to the site at rates of 0, 4, and 8 tons per acre prior to planting. Ash treatments had a positive effect on soil physical and chemical properties but had no impact on the survival or growth of any of the varieties in this trial.

INTRODUCTION

Wood fiber is the raw material that supports an extensive paper and oriented strand board industry in Michigan. Wood is also nature's battery for storing solar energy. While wood provides the primary energy source today for nearly half of the world's population (who use it primarily for cooking), it has only recently seen a resurgence of importance in the "developed" world. Half of Michigan's renewable energy is derived from wood; primarily used by the wood products and electricity industries. All of this wood presently comes from trees harvested in natural stands or plantations that are managed using traditional forestry techniques. It is possible, however, to grow wood fiber more quickly than in natural stands if intensive forest management systems are employed. Intensive systems require careful species selection, meticulous site preparation, control of weeds, fertilization, pest control, and occasionally irrigation (Stoffel, 1998). They are therefore more costly and complicated to employ than traditional systems. Because intensive forest management systems begin to resemble agriculture more than forestry, this concept has come to be called Short Rotation Fiber Farming.

Fiber Farms produce more fiber per unit of land and time than natural stands. The time between establishment and harvest of native aspen forests using traditional management systems in the Lake States region is usually about 50-80 years (according to the U.S. Forest Service's North Central Region's Web-based Forest Management Guide). Fiber Farms promise to shorten that time, for some types of fiber, to less than 20 years (Anonymous, 2002; Netzer, *et. al.*, 2002). If true, current fiber production could be quadrupled on some sites – creating opportunity to expand wood-using industries. Alternatively, fewer acres may be required to produce the same amount of wood fiber presently consumed by forest industry – freeing some areas for alternative uses.

Shorter rotations allow the fiber producer to respond more rapidly to changes in demands from the fiber market. Short rotations also allow the producer to realize a return on his initial investment sooner than would be possible under traditional forestry practices. This is a business model that is appealing to many forest land owners in Michigan. Short Rotation Fiber Farming is particularly suitable for people with small parcels, retired agricultural fields, or to those looking for alternatives to Christmas tree production.

At the time this test was initiated, Fiber Farming had been well established in the Pacific Northwest and was gaining popularity in Wisconsin and Minnesota (Riemenschneider, *et. al.*, 1996) but had yet to be adopted in Michigan. Researchers in the other Lake States had found that varieties from the genus *Populus* grew well in Fiber Farms and were valuable to forest products industries. European larch (*Larix deciduas*), which produces a completely different type of fiber, was another species with the potential to respond to intensive management in Fiber Farms. Although researchers in Michigan had conducted screening of various larch species and poplar varieties for many years, little work had been done to develop Fiber Farming techniques for these species in the state. This project was undertaken to gain experience and refine these techniques for sites in Michigan's Upper Peninsula and to obtain information about yields and pest resistance for some of the varieties that had shown promise in other Lake States.

As a side issue, we wanted to examine how the application of wood ash to the site prior to planting would effect the soil and tree growth. Disposal of this waste product was a concern for Michigan's paper industry. Standard practice involved placing the ash in sanitary landfills but this was costly. Alternative, less expensive methods of disposal were of interest. Broadcast application of ash to agricultural land or to Fiber Farms was one possible disposal method. Here, we examined whether the application of ash had any effect on the soil and on growth and survival of trees in a Fiber Farm.

MATERIALS AND METHODS

Experimental Design:

The test was arranged in a randomized split-plot design. There were four blocks, three main-plots per block, and six sub-plots per main-plot. The main-plots comprised 3 levels of wood ash application (0, 4, and 8 tons per acre) and sub-plots comprised six tree varieties (described below). Each sub-plot was made up of 64 trees arranged in a square grid of 8 rows and 8 columns. Rows and columns were spaced 8' apart. Only the interior 16 trees were examined. The remaining trees formed a 2-row border that isolated the interior of the plot from competition effects of adjacent plots. Figure 1 is a photograph in which the plots can be distinguished.

Species and Varieties:

Plant materials were selected for inclusion in this test based on superior performance in other plantations in the upper Great Lakes region (Hansen, *et. al.* 1994) and on their availability in sufficient quantities to complete the experimental design. Three varieties of *Populus x canadensis*: NE-222 (var. *caudina*), DN-5 (cv. 'Gelrica'), and DN-34 (cv. 'Eugenei') and one variety of *P. nigra* x *P. maximowiczii* known as NM-6 were included. Cuttings of DN-34 were obtained from Hramor Nursery of Manistee, Michigan and cuttings of the other hybrid poplar varieties were obtained from the Pope Soil and Water Conservation District of Glenwood, Minnesota. Containerized seedlings of European larch (*Larix decidua*) were provided by MeadWestvaco. The seedlot chosen was Mead #96-02-01 which is from a 'Sudetan' seed orchard maintained by the Aspen and Larch Genetics Cooperative of the University of Minnesota and is referred to by them as seedlot #XLD-7-96. Bare-root seedlings of an aspen hybrid (*P. tremula* x *P. tremuloides* seedlot #XLD-T-296), also developed by the Aspen and Larch Cooperative, were obtained from the Michigan Department of Natural Resources' Brighton Tree Improvement Center.

<u>Site Selection and Plantation Establishment:</u>
An eight-acre agricultural field at Michigan State University's Forest Biomass Innovation Center (FBIC) in Escanaba, MI was selected for the test. The site was fairly level with deep, fine sandy loam soil of the Onaway series. These soils are well drained with high moisture capacity and high natural fertility with nearly neutral pH – excellent for agricultural or forestry[1]. Escanaba averages 28" of precipitation annually, 140 frost-free growing days, and 1,171 growing degree days[2]. The site had been continuously used for agriculture during the previous 100 years, most recently for hay production and pasture.

Vegetation on the site was killed in the spring of 1997 with an application of glyphosate. The site was then plowed to a depth of 7" and repeatedly cultivated throughout the 1997 growing season. An 8'-tall, electric fence was constructed during the summer of 1997 to exclude white-tailed deer from the test area.

Wood ash from a boiler at the MeadWestvaco paper mill in Escanaba was evenly applied at 0, 4, and 8 tons per acre to randomly chosen main plots within each of the four blocks in October of 1997. This ash was incorporated into the top 6" of the soil with a standard agricultural cultivator.

Aspen and larch seedlings and un-rooted cuttings of the four hybrid poplar varieties were planted in May of 1998. The spring of 1998 was exceptionally dry and so the plantation was watered twice during May, delivering a combined total of about 2.1 gallons of water to each tree. The herbicide linuron (Lorox®) was applied to all the poplar plots within two days of planting. Larch plots were hand-weeded as needed during the first year. This, together with mechanical cultivation, provided weed control during the first year.

<u>Plantation Maintenance:</u>
Weeds were controlled in the plantation using a combination of mechanical cultivations and broadcast applications of imazaquin (Scepter®) and pendimethalin (Pendulum®) in the spring of the second through fifth years. Larch plots were not treated with these chemicals but received applications of sulfometuron (Oust®). Grass that escaped these treatments was spot treated with sethoxydim (Poast®) or fluazifop (Fusilade®) which act only against C4 plants[3].

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[1] Soil Survey of Delta County and Hiawatha National Forest of Alger and Schoolcraft Counties, Michigan. USDA Soil Conservation Service.
[2] Michigan State Climatologist's Office. 30-year averages for the period 1951 through 1980. Growing degree days based on 50° F.
[3] All trees and most broadleaf weeds fix carbon using the Calvin-Benson cycle (the C_3 process). Grasses and sedges among others fix carbon using the Hatch-Slack cycle (the C_4 process).

Trees were reduced to single stems in the fourth and fifth years. Lower branches were pruned at these times to facilitate access throughout the plantation.

Composite soil samples were taken from each of the 12 main plots in August of 1999 and a standard agricultural soil analysis was performed at the MSU Soil Testing Laboratory. It was assumed that fertilization would be a standard (albeit expensive) practice in Short Rotation Fiber Farms (Hansen, *et. al.*, 1983). No standard fertility guidelines existed for hybrid poplar so fertilizer was applied at rates normally for a corn crop. Granular fertilizer was broadcast throughout the plantation in April of the third, fourth, and fifth growing seasons. Since the trees had not yet fully occupied the site at the start of the 3rd growing season, fertilizer was applied at half of the recommended rate in that year. The first application comprised 62 lbs/acre of elemental nitrogen (urea), 5 lbs/acre of elemental phosphorus (diammonium phosphate), and 187 lbs/acre of elemental potassium (potash). The second two applications were made at the full rates recommended for corn; double the half-rate applied in the first application. Since fertilizer was applied to the entire plantation (there was no control), it was not possible to determine how tree growth might have differed without fertilization.

<u>Measurements and Analysis:</u>
As previously mentioned, measurements were made of the interior 16 trees of each sub-plot to avoid the uncharacteristic growth of trees on the plot edges. Tree survival and total height of trees was measured at the end of the 2nd, 3rd, 4th, 5th, 6th, 7th, 9th, and 10th growing seasons. Note that no measurements were made in the 8th year. Average height and survival of each variety was calculated and plotted over time (Figures 2 & 3). An analysis of variance in tree survival and height at age 10 was performed to identify significant differences among varieties and ash treatments.

Diameter at breast height[4] (DBH) was measured along with tree heights on any tree that was tall enough. Individual tree biomass was calculated using these DBH measurements at each measurement interval using an allometric equation developed at FBIC for trees like these by Miller (2016).

$$Tree\ Biomass\ (lbs) = DBH(inches)^2 \times 3.0657$$

All the trees in the measurement plots were harvested and chipped after the 11th growing season and their combined green weight was recorded. Moisture content of each plot's chips was determined by comparing the weight of a five pound sub-sample before and after drying at 220°F to a constant weight. Standing biomass in each plot was expressed on an areal basis in dry tons per acre throughout the life of the plantation using either the calculated or actual values and plotted over time (Figure 4). An analysis of variance in 11th-year plot biomass was conducted to identify significant differences among varieties and ash treatments.

Paper and oriented strand board manufacturers purchase fiber as "pulp sticks" which are usually 100" long and a minimum of 3-½" in diameter. These are often purchased in units of cords not tons. Since Short Rotation Fiber Farms are a potential source of material for these manufacturers,

[4] Diameter at breast height is measured 4.5' above the ground on the stem.

the number of pulp sticks in each measurement plot was tallied after ten years. A one cord pile (4'-wide, 4'-tall, and 8' long) was constructed at the time of plantation harvest. A photograph of this pile is included in the appendix. It took 51 randomly assorted sticks to complete the one cord pile. Thus, by dividing the total number of sticks tallied in each plot by 51, it was possible to estimate each plot's volume in cords.

Tree damage from insects and diseases was monitored throughout the life of the plantation and scored whenever it became widespread. Cankering caused by *Septoria musiva* (in the case of the poplar hybrids) and *Hypoxylon mammatum* (in the case of aspen) was scored in the 5^{th}, 6^{th}, 7^{th}, and 9^{th} year. Infection by a butt rotting fungi (probably *Armillaria mellea*) was noticed in the 9^{th} year.

RESULTS AND DISCUSSION:

Ash Treatment Effects:
An analysis of ash and variety interactions with soil chemical and physical properties was conducted after seven growing seasons. In summary, increasing ash application and greater biomass growth tended to increase formation of soil macroaggregates which, in turn, improved soil water holding capacity and increased soil organic carbon levels (Blanco-Canqui, *et. al.* 2007). Increasing ash application levels also tended to improve the soil properties important to the long-term productivity of fast-growing plantations (*e.g.* increased pH, N, Ca^{2+}, Mg^{2+}, and reduced extractable acidity) and also enhanced long-term soil carbon sequestration (Sartori, et. al. 2007).

Despite these physical and chemical changes to the soil, wood ash treatments had no measurably significant effect on tree height, diameter, survival, or biomass yield after 11 years. This would indicate that up to 8 tons per acre of wood ash can be applied to benefit soils like these with neither good nor bad effects to the trees. The Onaway soil at this site was reasonably fertile and had a fairly high starting pH (ranging from 5.9 to 6.2 according to the MSU Soil Testing Laboratory). Tree growth on sites with lower starting pH may benefit more from the addition of wood ash.

European Larch:
Larch was included in this trial because the collaborating paper company was interested to know how it would respond and grow in Short Rotation Fiber Farms. Although the European larch included in this test survived as well as the best poplar hybrid, larch growth was vastly inferior to that of poplar during the 11 years of this test (Table 1). Other experience with this variety in the Lake States suggests that larch is a promising softwood species for pulpwood, but that longer rotations are needed to produce adequately sized trees. The poplars in this trial followed an entirely different growth trajectory (Figure 3), growing twice as tall and producing three times as many pulp sticks as larch.

Aspen:
The aspen hybrid included in this trial was a cross between the North American and European trembling aspens. Hybrids from this group are of particular interest to the local paper industry because their fibers are most similar to the native North American aspens. The aspen variety

tested here survived and grew significantly less well than any of the other poplar varieties. Ultimately, the aspen produced 19% less biomass and 35% fewer cords than the next closest variety (DN-34) and 55% less biomass and 72% fewer cords than the best performing variety (NM6) (Table 1). The aspens certainly have desirable fiber characteristics and may be better adapted to the insects and pests of the Lake States region but, like the larch discussed above, they obviously require more than 11 years to develop into commercially viable biomass or pulpwood trees under conditions like these.

Survival and Growth of "DN" and "NM" Hybrids:
Survival of these varieties was consistent across blocks but height and biomass differed significantly among the blocks. After accounting for that variation, significant differences among the four non-aspen varieties were evident (Table 1). NM6 produced the most biomass, yielding nearly 40 dry tons per acre after 11 years; a mean annual increment of 3.6 dry tons/acre-year. This is well within the observed range of poplar yields throughout the United States (Volk, *et. al.*, 2018). NE222 was equally as tall but produced only 28 dry tons per acre of biomass; a mean annual increment of 2.5 dry tons/acre-year. DN5 and DN34 were significantly shorter than NM6 and NE222 and only produced an average mean annual increment of 2.0 dry tons/acre-year.

What is not obvious from these data but was strikingly apparent on the ground, was the ability of NM6 to fully occupy the growing space and exclude all weed competition in as little as three years. The efficiency with which this variety used solar radiation (and presumably soil resources as well) easily accounts for its superior growth and yield.

All of the non-aspen varieties in this trial grew large enough to produce pulpwood sticks. This is important for consumers that require roundwood rather than whole-tree chip feedstocks. Commercial *Populus tremuloides* stands in the Lake States can be expected to produce 20-30 cords per acre in 50-70 years on reasonable sites. The NM6 trees in this trial had produced 571 pulp sticks per acre after 10 years (Table1). That is the equivalent of 11 cords per acre in just 10 years; more than half of the volume expected from a natural stand five times as old. It is noteworthy that each NM6 tree in this trial had produced an average of only one single pulp stick but were already 46' tall and thus approaching a size that would soon yield a second pulp stick – and significantly more roundwood volume. However, it was not clear that all of these trees would live long enough to yield that second pulp stick.

Damaging Agents:
The Achilles heel of most hybrid poplars in the Lake States is their susceptibility to damage caused by insects and diseases (Ostry, *et. al.* 1989). Cankering by *Hypoxylon mammatum* in the case of aspen and *Septoria musiva* in the case of the other poplars gradually increased between the 5th and 9th years in this trial (Table 2). DN5 was particularly susceptible – almost half of all these trees were cankered by age nine. Roughly 20% of the trees of other poplar varieties were cankered by the ninth year. A butt rotting fungus (probably *Armillaria mellea*) became established in the plots of DN5 and nearly 50% of all those trees were infected by the end of the 6th year. The other poplar varieties were relatively free of this problem. The combination of cankering and butt rot may have been responsible for the increasing mortality of DN5 trees (Figure 2).

NM6 trees have shown susceptiblity to wind breakage in other fast growing plantations in the Lake States. Nine percent of the trees in NM6 plots here were broken in high winds during fifth and sixth growing seasons. Side branches in these broken trees quickly obtained dominance and formed new tops. Tree growth was undoubtedly reduced as a result of this early damage, but NM6 still achieved superior height and biomass production by the end of the trial. The brittle nature of rapidly growing NM6 may be indicative of poor fiber characteristics but it apparently does not detract from biomass growth.

SUMMARY

- The best poplar variety tested (NM6) achieved a mean annual biomass increment of 3.6 dry tons per acre-year and had produced 11 cords per acre after 11 years. These yields are comparable to other poplar trials throughout the United States and far superior to native stands of aspens in the Lake States region.
- NM6 was able to completely capture the growing space in its plots in three years and was so efficient at intercepting sunlight that no weeds were able grow under its canopy after that year.
- European larch and aspen hybrids may be promising fiber crops in the Lake States on longer rotations than the 11 years tested here.
- Wood ash application up to 8 tons per acre to Short Rotation Fiber Farms improved physical and chemical soil properties, but had no effect on the poplar growth observed here.
- Between 20% and 50% of all the poplar trees in this trial were damaged by cankering fungi after 11 years and survival was beginning to decline. Tree health, rather than yield, is the most challenging problem to be overcome for these varieties if they are to become commercially viable in this part of the country.

ACKNOWLEDGEMENTS

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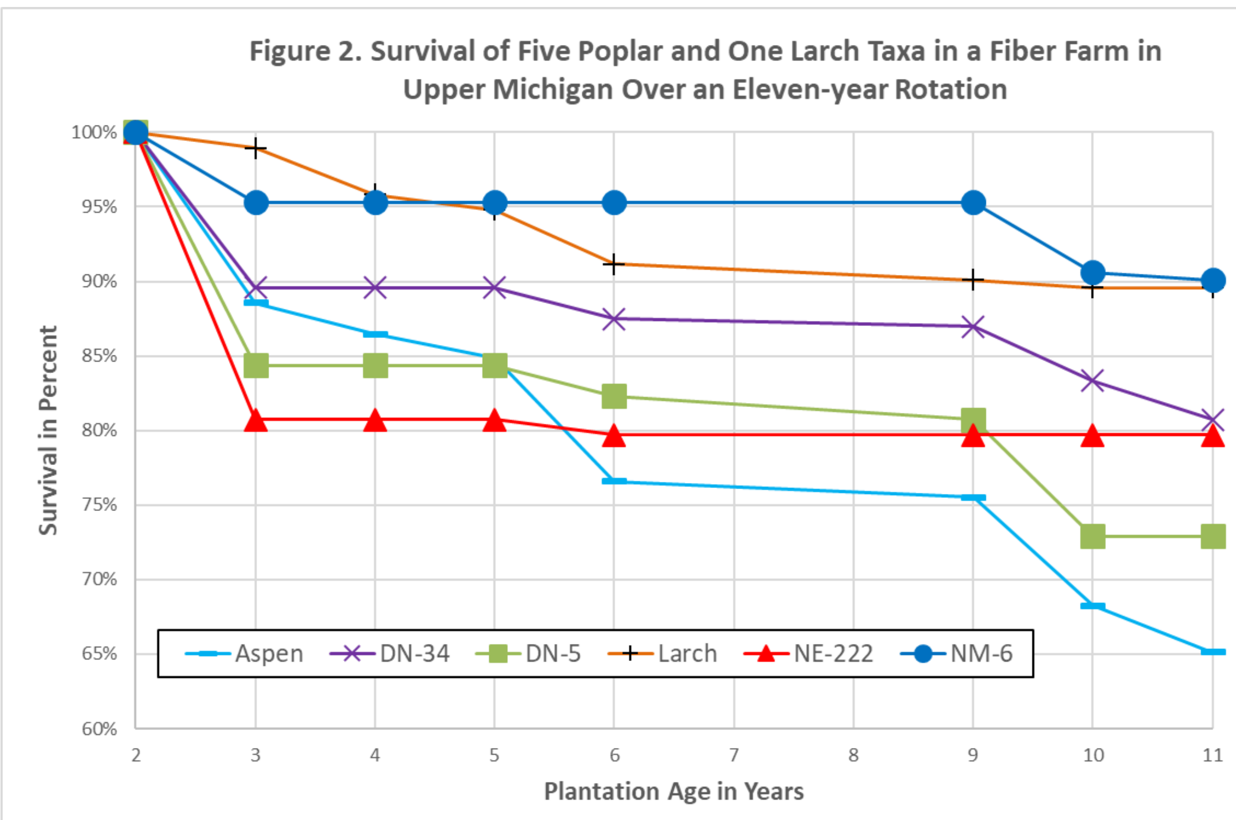
Figure 1. An aerial over-view of the Escanaba Fiber Farm



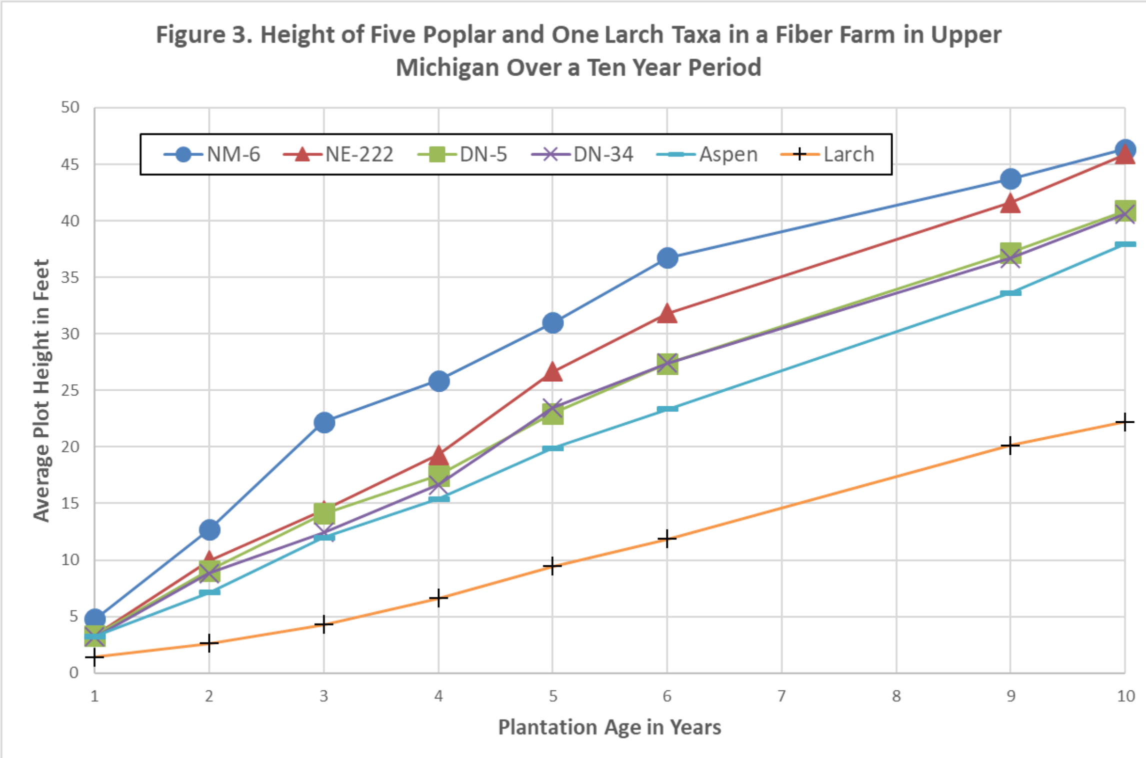


Figure 3. Height of Five Poplar and One Larch Taxa in a Fiber Farm in Upper Michigan Over a Ten Year Period
NM-6
NE-222
DN-5
DN-34
Aspen
Larch
Average Plot Height in Feet
Plantation Age in Years

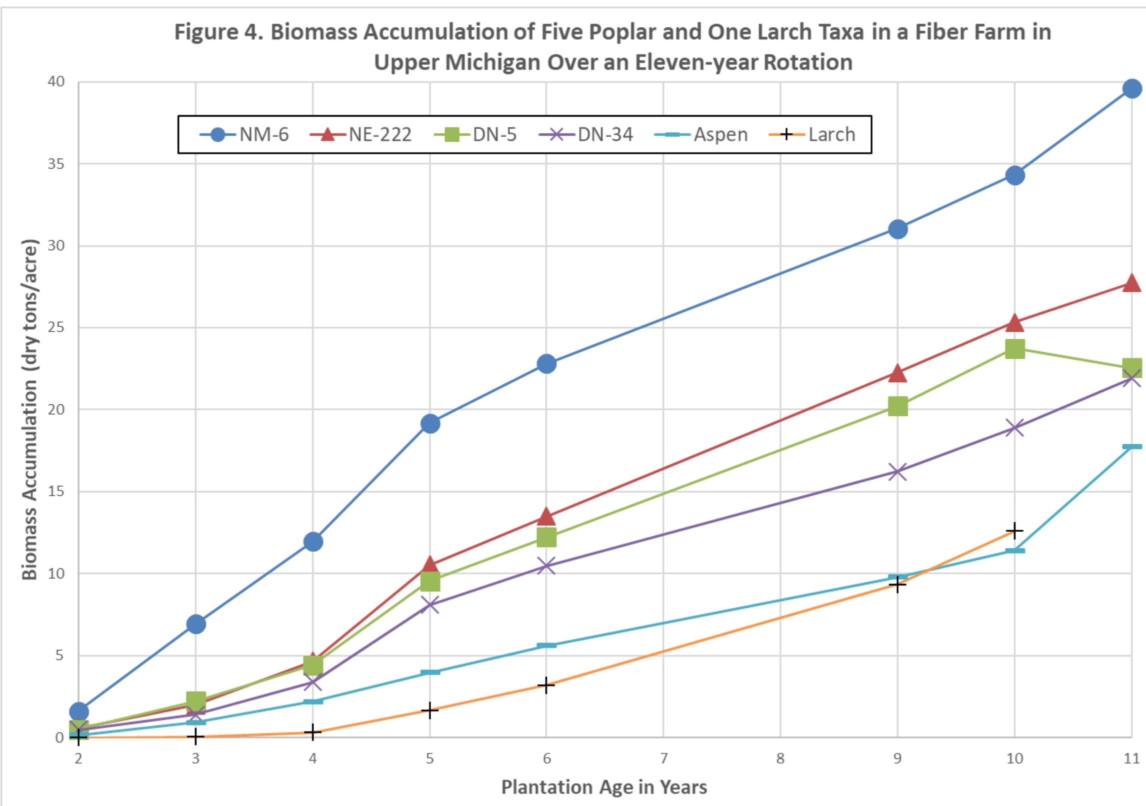


Figure 4. Biomass Accumulation of Five Poplar and One Larch Taxa in a Fiber Farm in Upper Michigan Over an Eleven-year Rotation
NM-6
NE-222
DN-5
DN-34
Aspen
Larch
Biomass Accumulation (dry tons/acre)
Plantation Age in Years

Table 1. Survival, Height, Pulpwood, and Biomass of five poplar and one larch taxa
in a fiber farm in Escanaba, MI.
Tree survival, height, and pulpwood estimates were made after year 10
and biomass was measured during harvest after year 11.

Taxa	*Survival*		*Tree Height (ft)*		Pulpwood Estimates		*Total Biomass Age 11 (dry tons/acre)*	
					100" Sticks per acre	*Cords per Acre*		
NM-6	90%	a	46.3	a	571	11.2	39.59	a
NE-222	80%	b	45.9	a	418	8.2	27.73	b
DN-5	73%	c	40.9	b	383	7.5	22.54	c
DN-34	81%	b	40.6	b	245	4.8	21.90	c
Aspen	65%	d	37.9	c	160	3.1	17.73	d
Larch	90%	a	22.2	d	50	1.0		

Survival, Height, and Biomass means followed by the same letter are not significantly different (α = 0.05)

The number of sticks was recorded in each 16-tree plot and summed across all plots for each taxa. A separate test revealed that 51 of these sticks were required to form a 1-cord pile of pulpwood.

Analysis of 200 trees (including a range of diameters of each taxa) determined that pulp sticks accounted for 55% of the total tree weight and the remainder (45%) was in top biomass.

Table 2. Proportion of trees with Septoria cankers
in a fiber farm in Escanaba, Michigan
(192 total trees of each taxa observed)

Taxa	***Year 5***	***Year 6***	***Year 7***	***Year 9***
DN-5	8%	9%	20%	47%
DN-34	3%	7%	21%	23%
NM-6	8%	11%	19%	20%
Aspen	5%	10%	15%	20%
NE-222	1%	2%	16%	17%

<table>
<tr><td>Applying wood ash to main plots of future fiber farm.</td><td>Applying fertilizer in 3rd year.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Stem canker resulting from Septoria infection.</td><td>A 5-year-old NM6 plot with no undergrowth.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Harvesting at age eleven.</td><td>One cord of pulp sticks.</td></tr>
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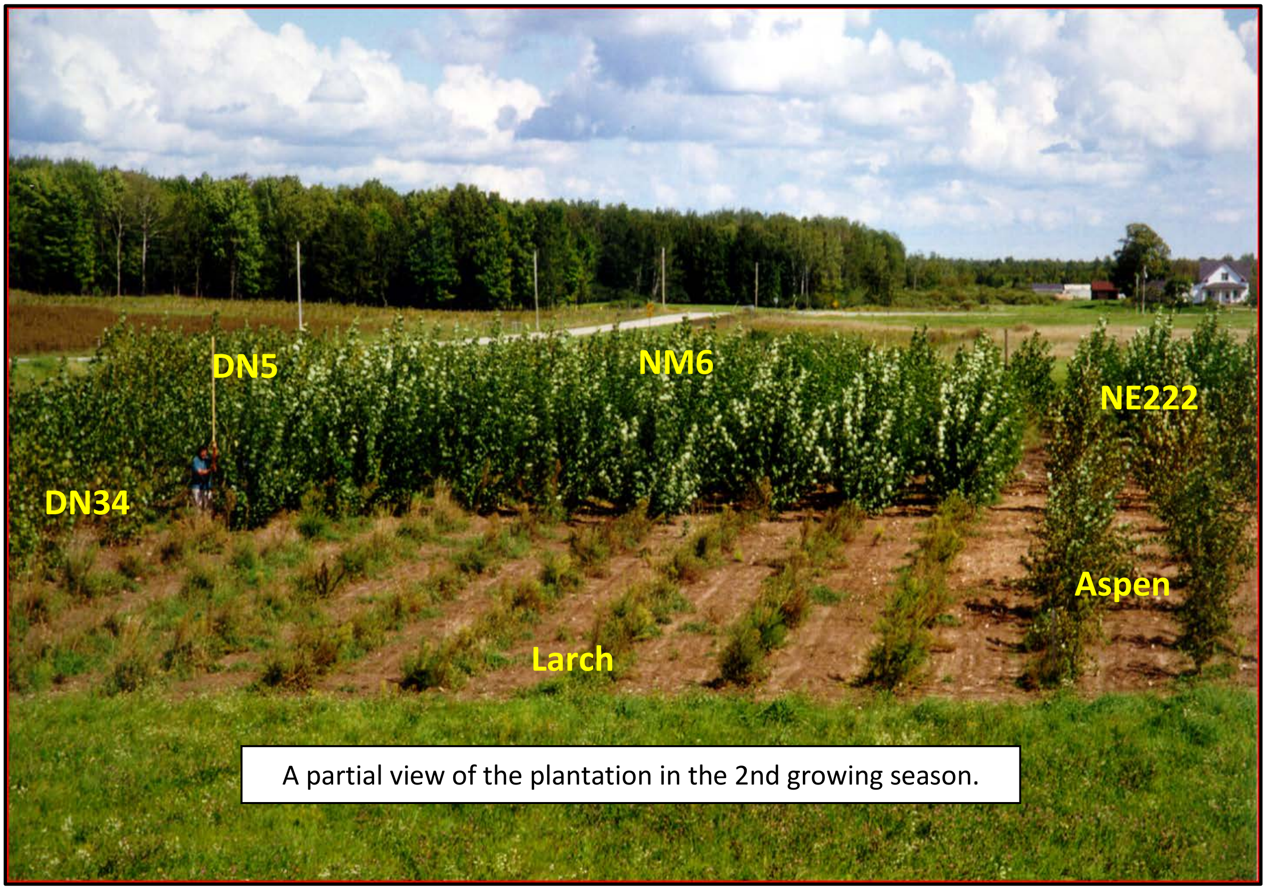

A partial view of the plantation in the 2nd growing season.

An advanced irrigation system…
…employed during the 1st growing season.