THREE POPLAR HYBRIDS SHOW NO GROWTH RESPONSE TO SEVEN LOW RATES OF CONTROLLED-RELEASE FERTILIZER APPLICATION TWO YEARS AFTER ESTABLISHMENT IN MICHIGAN'S UPPER PENINSULA.

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Managing plant nutrition has long been recognized as directly related to adequate plant growth and to production system finances. Controlled-release fertilizer formulations were developed over 30 years ago as a way to provide nutrition evenly during the growth cycle and avoid nutrient loss through leaching and run-off that occurs when applications are made in periodic pulses. These time-release products are initially more expensive than traditional formulations. But because they promise improved nutrient use efficiency and lower nutrient loading in ground and surface water, the impact on total system finances may be positive. To date, controlled-release fertilizers have been used effectively in greenhouse and nursery applications and more recently are being used in established orchard and landscape tree crops.

Short rotation woody crop (SRWC) plantations can rapidly produce large amounts of fiber and biomass when managed intensively. These production systems rely on fast growing hybrids from the genera *Salix* (willow) and *Populus* (poplar) and are capable of annually producing more than 9-18 dry Mg/ha (4-8 dry tons/acre) of biomass on 3- to 8-year rotations. Managing plant nutrition with controlled-release fertilizers may be one way to further refine these SRWC systems to reduce costs, improve yield, and minimize environmental impacts.

A trial was established at Michigan State University's Forest Biomass Innovation Center in Escanaba, MI on June 1, 2015 to examine the impact of several controlled-release fertilizer formulations when applied at different rates and times to three varieties of poplar hybrids. The controlled-release fertilizer formulations provided by ICL Specialty Fertilizers have several potential advantages over traditional formulations; 1) fertilizer may be applied simultaneously with planting, 2) nutrients will be released gradually throughout the growing season, and 3) placing the fertilizer immediately adjacent to the tree may maximize availability to the crop and not to the weeds.

Three fertilizer products were received from ICL Specialty Fertilizers in May of 2015. These formulations were designed to release their elements either in 5-6 months or in 8-9 months, dependent on soil temperatures. Eight fertility treatments were tested (Table 1). One of these eight treatments was a control and received no fertilizer. Dormant hardwood cuttings (24cm or 9.5" long) of three hybrids of *Populus deltoides* and *P. nigra* (known by their NRRI number designators: 99038022, 99059016, and 9732-31) were obtained from the University of Minnesota's Natural Resources Research Institute (NRRI). These varieties had shown good adaptability and growth in previous Michigan tests.

Summary of Fertilizer Treatments

Treatment #	*Weight of product per*	*Bag Code*	*Formulation*	*Lbs (elemental) per acre** N	P	K	*Longevity*	*Year of Application*
1	15 gm/tree	PC15089	9-20-8+MgO+Boron	4	4	3	5-6 months	1&2
2	30 gm/tree	PC15089	9-20-8+MgO+Boron	8	8	6	5-6 months	1&2
3	15 gm/tree	PC15084	9-20-8+MgO+Boron	4	4	3	8-9 months	1&2
4	30 gm/tree	PC15084	9-20-8+MgO+Boron	8	8	6	8-9 months	1&2
5	30 gm/tree	PC15084	9-20-8+MgO+Boron	8	8	6	8-9 months	1
6	15 gm/tree	PC15176	18-0-18+MgO	8	0	7	8-9 months	1&2
7	30 gm/tree	PC15176	18-0-18+MgO	16	0	13	8-9 months	1&2
8	0	none	0	0	0	0	0	0

* - NOTE: Fertilizer was applied at the bottom of a small hole near each planted tree and NOT broadcast over the entire area. The equivalent application in pounds per acre was calculated here given that each tree occupied a 4' X 8' area, or 0.0007346 acres. Thus, approximately 1,361 doses of product were applied per acre.

Preparation and Establishment: A sod-covered site was prepared for planting by spraying glyphosate twice during May, 2015 to kill existing vegetation. The site was cultivated at the end of May to a depth of 25cm (10”). The dormant cuttings were inserted in the ground to their full length on June 1, 2015. The test was arranged in a split-plot randomized block design with four blocks of 8 fertilizer treatments (the main plots) and three poplar varieties (the sub-plots) (Attachment1). Each sub-plot was composed of a row containing six cuttings (clones) of a single poplar variety. Cuttings were planted 1.2m (4’) apart in rows and the rows were 2.4m (8’) apart. Extra space (3.6-4.9m or 12-16’) was left between the main plots to isolate them from one another. Fertilizer was applied immediately after planting in 24cm (9.5”) deep holes punched within 10cm (4”) of each cutting. Post planting weed control herbicides (imazaquin and pendamethalin) were applied four days after planting. A deer exclosure fence was erected around the site one week after planting. The fence effectively eliminated deer damage on the test trees.

Maintenance: The site was constantly monitored throughout the summer of 2015. Trees that had not sprouted were replanted with new cuttings on July 7, 2015. Whenever the ground became excessively dry the trees were hand watered. Approximately one gallon of water was applied to each tree each time irrigation was required. Irrigation was applied three times (July 24 and 30 and August 12). Weeds that began to invade the site were treated with spot applications of glyphosate in early August, 2015. Weed control was excellent throughout the first year. A trencher was pulled between all the main plots on August 13 and again on November 24, 2015 to ensure that no roots migrated between plots.

Fertilizer was reapplied in plots designated to receive that treatment (Table 1) on March 14, 2016 using the same procedure as in the previous spring. Imazaquin and pendamethalin were broadcast over the entire test on March 19, 2016 and a directed application of glyphosate was applied to kill actively growing weeds on March 20th, June 17th, and August 1st, 2016. Weed control was adequate in the second year. The trencher was pulled between the main plots on March 18th, May 17th, and again on August 3rd, 2016 to minimize root growth between main plots.

Measurements: The planting site is located on a level area that had been an agricultural field prior to this test. The soil is classified as an Onaway Fine Sandy Loam. Composite soil samples from the top 23cm (9”) of the soil were collected from each of the 32 main plots on July 15, 2015. These samples were sent to MSU’s Soil and Plant Nutrient Laboratory for analysis (Attachment 2). Although the test location was small (0.29 ha or 0.7 acres) chemical analysis of the soil in the 32 main plots was surprisingly variable (Attachment 2). For example, pH ranged from 5.8 to 7.5, phosphorus levels ranged from 11 to 250ppm, and potassium levels ranged from 33 to 151ppm. Main plot soil chemistry factors were subsequently used as co-variates in the analysis of variance in growth traits.

Heights of all trees were measured on August 14 and October 5, 2015, and again on August 18, 2016. An analysis of variance in tree heights found no significant differences among the fertilizer treatments. It was decided that plot biomass might be a better indicator of fertilizer effects, so all the trees were cut and weighed on November 1, 2016. Moisture content was determined by placing samples of this material in a drying oven at 220ºF until completely dry. This information was used to convert each sub-plot’s field green weight to oven-dry biomass.

An analysis of variance in dry biomass (both average stool weight and whole plot weight) showed significant differences among the three poplar varieties tested and among the four blocks but no significant differences among the applied fertilizer treatments. Analysis of variance in biomass production among different treatment factors (total elemental applications of N, P, and K; application rates of Mg or B; frequency of application, and fertilizer release rate) also found no significant differences. Adding plot survival and the soil chemistry characteristics of the main plots as covariates to the analysis of variance did not improve the discriminating power enough to find any significant differences among any of the fertility treatment factors.

Average performance within the sub-plots is reported in the series of tables included in Attachment 3. Each table presents average plot weight, average stool weight, average stem height, tallest stem height, and plot survival for a particular effect in the experiment:

1. Poplar variety
2. Block (replication) designation
3. Treatment
4. Total elemental nitrogen applied
5. Total elemental phosphorus applied
6. Total elemental potassium applied
7. Magnesium level applied
8. Boron level applied
9. Fertilizer formulation used
10. Frequency of fertilizer application
11. Release rate of fertilizer

While growth differences among poplar varieties and blocks were significant, growth differences among fertilizer related traits were not. Keeping in mind that growth differences were not statistically different, the performance trends shown in all the tables of Attachment 3 were neither regular nor systematic. For example, average plot weight was essentially the same for plots in which no nitrogen was applied as in plots where 32 pounds of elemental nitrogen was applied. Yet plots receiving intermediate levels of nitrogen (8 and 16 pounds) produced more biomass than plots receiving either of the extreme rates. Similar non-linear patterns are evident in all of the tables in Attachment 3 and are indicative of random, rather than systematic variation among the treatments.

The correlation among growth parameters measured at the end of the second growing season is presented in Table 2. It was assumed that analyzing actual tree weights rather than just stem heights would provide better discrimination among fertilizer treatments. This was not the case. Plot average stem height was strongly and significantly correlated with both total plot dry weight (r^2=0.828) as well as average stool dry weight (r^2=0.895). Since stem heights are much easier to obtain than stem biomass (which requires destructive sampling of the subject trees and a great deal of weighing, sub-sampling, drying, and re-weighing), it is suggested that future comparisons of fertility treatments in young plantations like this one can be made with sufficient precision on the basis of average plot stem heights alone.

Discussion: None of the fertility treatments applied here could be seen to produce a positive effect on tree growth or survival after two growing seasons. Even after accounting for the variation caused by poplar variety, block differences, tree survival, and plot soil chemical properties, there was still too much unexplained variation in the test to be able to discern any significant fertilizer treatment effects. Unexplained within-plot variation has been common in other poplar and willow hybrid trials in Michigan and was strongly evident here. If there were fertilizer effects, they were too small to be seen amid this unexplained variation in this particular experimental design.

On the other hand, it is possible that there really were no effects from these fertilizer treatments because they were (1) incorrectly placed, (2) were poorly timed, or (3) were not sufficiently large or properly balanced to be useful to these trees. It is reasonable to discount the first two problems because the fertilizer applications were made within 10cm of each tree and the controlled-release nature of the formulations provided fertilizer throughout the growing season.

It is more likely that the quantity of fertilizer material or the formulations applied here were simply insufficient to produce a growth response in these trees. Traditional fertilizers in Christmas tree plantations are often broadcast at rates of at least 100+ pounds of elemental N, 35 pounds of elemental P, and 60 pounds of elemental K per acre. Only a fraction of that was applied here (*i.e.* 8 pounds/acre of N, 8 pounds/acre of P and 6 pounds/acre of K as shown for Treatment #2 in Table 1). In fact, the amount of product applied here on an areal basis was about one tenth the rate recommended by Everris for broadcast field applications of similar products. This low application rate was chosen with the assumption that placing the fertilizer close to the developing tree would overcome its need to spread roots everywhere in order to collect fertilizer that had been broadcast over the entire area. The hypothesis was that by placing the fertilizer close to the cutting, the tree rather than the weeds would benefit and that much less fertilizer (on an areal basis) would be required to produce a growth response. That apparently did not happen here.

The principle of obtaining improved growth in short rotation woody crop plantations using advanced fertilizer formulations that (1) deliver nutrients to the crop rather than to the weeds, (2) improve nutrient uptake efficiency, and (3) reduce nutrient migration away from the site is environmentally and economically sound and worth pursuing. Consequently, additional work is warranted to find appropriate formulations, rates, and methods of application of these new advanced fertilizer formulations in short rotation woody crop production systems.

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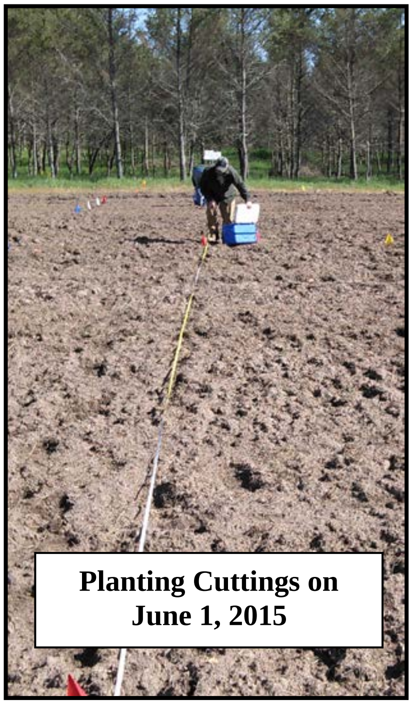
Table 2: Correlations among various stem, stool, and plot growth variables in a poplar fertilizer trial in Escanaba, MI after two growing seasons.

		PlotDryWt	StoolDryWt	AveHt	MaxHt	Survival	Stems/Stool
PlotDryWt	Pearson Correlation	1	.926**	.828**	.693**	.506**	.097
	Sig. (2-tailed)		.000	.000	.000	.000	.346
	N	96	96	96	96	96	96
StoolDryWt	Pearson Correlation	.926**	1	.895**	.730**	.185	.095
	Sig. (2-tailed)	.000		.000	.000	.071	.357
	N	96	96	96	96	96	96
AveHt	Pearson Correlation	.828**	.895**	1	.804**	.154	-.060
	Sig. (2-tailed)	.000	.000		.000	.133	.562
	N	96	96	96	96	96	96
MaxHt	Pearson Correlation	.693**	.730**	.804**	1	.189	.013
	Sig. (2-tailed)	.000	.000	.000		.066	.902
	N	96	96	96	96	96	96
Survival	Pearson Correlation	.506**	.185	.154	.189	1	.039
	Sig. (2-tailed)	.000	.071	.133	.066		.703
	N	96	96	96	96	96	96
Stems/Stool	Pearson Correlation	.097	.095	-.060	.013	.039	1
	Sig. (2-tailed)	.346	.357	.562	.902	.703	
	N	96	96	96	96	96	96

**. Correlation is significant at the 0.01 level (2-tailed).



Planting Cuttings on June 1, 2015

Applying Fertilizer on June 1, 2015

Measuring Heights on August 14, 2015

Measuring and Weighing on November 1, 2016

Attachment 1: Plantation Map. This plantation is located at MSU's Forest Biomass Innovation Center in Escanaba, Michigan in an area identified as U08bh. There are four blocks, with 8 main plots each. Main plots contain the eight fertilizer treatments (see Table 1 for a list of these treatments). Each main plot is divided into 3 sub-plots that contain the three poplar hybrids (here identified as Clone A, B, and C and identified as Yellow, Red and Blue in Attachment #3 of this report – see that text for the NRRI identifier for each hybrid). NORTH IS TO THE RIGHT ON THIS MAP.

Column Number (from right to left); **Row Number (from top to bottom)**

Row	18 17	16 15	14 13	12 11	10 9	8 7	6 5	4 3	2 1
1	Cln A			Cln A			Cln B		
2	Cln B	Trt 4	Blk 1	Cln B	Trt 8	Blk 2	Cln A	Trt 1	Blk 3
3	Cln C			Cln C			Cln C		
4	Cln A			Cln C			Cln B		
5	Cln B	Trt 2	Blk 1	Cln B	Trt 1	Blk 2	Cln C	Trt 5	Blk 3
6	Cln C			Cln A			Cln A		
7	Cln B			Cln B			Cln C		
8	Cln C	Trt 5	Blk 1	Cln A	Trt 4	Blk 2	Cln B	Trt 6	Blk 3
9	Cln A			Cln C			Cln A		
10	Cln A			Cln C			Cln C		
11	Cln C	Trt 6	Blk 1	Cln A	Trt 3	Blk 2	Cln A	Trt 3	Blk 3
12	Cln B			Cln B			Cln B		
13	Cln A			Cln C			Cln C		
14	Cln C	Trt 3	Blk 1	Cln A	Trt 7	Blk 2	Cln A	Trt 7	Blk 3
15	Cln B			Cln B			Cln B		
16	Cln C			Cln C			Cln B		
17	Cln A	Trt 7	Blk 1	Cln B	Trt 5	Blk 2	Cln A	Trt 2	Blk 3
18	Cln B			Cln A			Cln C		
19	Cln B			Cln C			Cln B		
20	Cln C	Trt 1	Blk 1	Cln A	Trt 2	Blk 2	Cln C	Trt 8	Blk 3
21	Cln A			Cln B			Cln A		
22	Cln C			Cln A			Cln B		
23	Cln A	Trt 8	Blk 1	Cln C	Trt 6	Blk 2	Cln C	Trt 4	Blk 3
24	Cln B			Cln B			Cln A		
25	Cln C			Cln A			Cln C		
26	Cln B	Trt 5	Blk 4	Cln B	Trt 3	Blk 4	Cln B	Trt 6	Blk 4
27	Cln A			Cln C			Cln A		
28	Cln A			Cln A			Cln B		
29	Cln B	Trt2	Blk 4	Cln B	Trt 7	Blk 4	Cln C	Trt 1	Blk 4
30	Cln C			Cln C			Cln A		
31	Cln B			Cln A					
32	Cln A	Trt 4	Blk 4	Cln B	Trt 8	Blk 4			
33	Cln C			Cln C					

Attachment 2. Soil Analysis of poplar fertility trial site. Composite samples from the top 9" of soil were taken from each of 32 main plots and summarized here.

Soil Analysis Summary - Poplar fertility trial, Escanaba, MI												
Values & Statistics	pH	Nitrate-N (ppm N)	Ammonium-N (ppm N)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Boron (ppm)	Cu (ppm)
	SMP buffer method	1M KCl method		Bray P1 method	Neutral Ammonium Acetate method			0.1M HCl method				
BLOCK 1												
Average	6.1	31	7	45	74	1064	99	5	39	11	0	2
95% Confidence interval (+/-)	0.9	20	3	85	66	714	82	9	29	40	0	1
Minimum	5.5	20	5	14	38	745	67	2	24	1	0	1
Maximum	7.1	51	10	145	136	1921	194	15	71	60	1	3
BLOCK 2												
Average	6.3	24	6	30	66	950	91	3	28	6	0	1
95% Confidence interval (+/-)	0.7	24	4	42	39	387	55	2	5	12	0	1
Minimum	6.0	12	4	13	41	797	64	2	24	1	0	1
Maximum	6.2	33	11	33	90	1051	114	4	40	16	0	2
BLOCK 3												
Average	6.0	23	6	19	46	874	85	2	33	6	0	1
95% Confidence interval (+/-)	0.3	15	5	16	37	295	38	2	9	11	0	1
Minimum	5.8	14	4	11	33	658	54	2	27	1	0	1
Maximum	6.2	33	11	33	90	1051	114	4	40	16	0	2
BLOCK 4												
Average	6.9	28	7	130	117	1523	155	16	80	36	1	3
95% Confidence interval (+/-)	0.7	13	3	161	56	589	59	15	83	19	0	1
Minimum	6.4	17	4	35	56	1051	118	7	26	23	0	3
Maximum	7.5	39	9	250	151	1847	198	28	140	53	1	4
TESTWIDE												
Average	6.4	26	7	56	76	1103	108	7	45	15	0	2
95% Confidence interval (+/-)	1	124	124	124	124	124	124	124	124	124	124	124
Minimum	5.8	12	4	11	33	658	54	2	24	1	0	1
Maximum	7.5	51	11	250	151	1921	198	28	140	60	1	4

Attachment 3: Performance of poplar hybrids after two growing seasons in a fertilizer trial at the Forest Biomass Innovation Center in Escanaba, MI. When treatment means are significantly different, the *Least Significant Difference* statistic is reported and significantly different means are followed by different letters of the alphabet. When no significant differences were detected, this fact is mentioned in the bottom row of each table.

Poplar Variety	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
Yellow	14.1a	2.6a	11.0	12.4	92%a
Red	11.4b	2.0b	10.3	12.2	96%a
Blue	7.8c	1.6c	10.0	12.2	80%b
L.S.D.	**1.92**	**0.33**	**NS**	**NS**	**7%**

Block	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
1	13.8a	2.5a	11.2a	13.1a	92%
2	11.5b	2.1b	10.9ab	12.6ab	89%
3	9.9b	1.9b	10.1bc	12.1bc	89%
4	9.2b	1.8b	9.6c	12.3ab	87%
L.S.D	**2.2**	**0.39**	**0.75**	**0.76**	**NS**

Treatment	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
3	12.8	2.3	10.8	12.9	90%
6	11.9	2.2	10.8	12.5	88%
8	11.1	1.9	10.1	12.2	96%
1	10.9	2.1	10.4	12.6	89%
4	10.9	2.0	10.3	11.9	92%
2	10.8	2.1	10.5	12.1	86%
5	10.5	2.0	10.6	12.3	89%
7	10.1	1.9	10.0	11.8	83%
No Significant Differences					

Nitrogen (lbs-elemental per acre)	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
8	11.4	2.1	10.6	12.6	89%
16	11.2	2.1	10.5	12.2	88%
0	11.1	1.9	10.1	12.2	96%
32	10.1	1.9	10	11.8	83%
No Significant Differences					

Phosphorus (lbs-elemental per acre)	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
8	11.4	2.1	10.6	12.6	89%
0	11.0	2.0	10.3	12.2	89%
16	10.9	2.0	10.4	12.0	89%
No Significant Differences					

Potassium (lbs-elemental per acre)	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
14	11.9	2.2	10.8	12.5	88%
6	11.4	2.1	10.6	12.6	89%
0	11.1	1.9	10.1	12.2	96%
12	10.9	2.0	10.4	12.0	89%
26	10.1	1.9	10.0	11.8	83%
No Significant Differences					

Magnesium Level	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
LOW	11.9	2.2	10.7	12.7a	89%
NONE	11.1	1.9	10.1	12.2b	96%
HIGH	10.6	2.0	10.4	12b	88%
L.S.D	**NS**	**NS**	**NS**	**0.54**	**NS**

Boron Level	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
LOW	11.9	2.2	10.6	12.7	90%
NONE	11.0	2.0	10.3	12.2	89%
HIGH	10.7	2.0	10.5	12.1	89%
No Significant Differences					

Formulation	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
9-20-8, Slow	11.4	2.1	10.6	12.4	90%
None	11.1	1.9	10.1	12.2	96%
18-0-18, Slow	11.0	2.1	10.4	12.2	85%
9-20-8, Fast	10.9	2.1	10.4	12.3	88%
No Significant Differences					

Frequency	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
Twice	11.2	2.1	10.5	12.3	88%
Never	11.1	1.9	10.1	12.2	96%
Once	10.5	2.0	10.6	12.3	89%
No Significant Differences					

Release Rate	*Plot Weight (dry-lbs)*	*Ave Stool Weight (dry-lbs)*	Average Height (feet)	*Tallest Stem (ft)*	*Plot Survival*
Slow	11.2	2.1	10.5	12.3	88%
None	11.1	1.9	10.1	12.2	96%
Fast	10.9	2.1	10.4	12.3	88%
No Significant Differences					