HYBRID POPLAR ESTABLISHMENT UNDER HARSH ENVIRONMENTAL AND EDAPHIC CONDITIONS

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ABSTRACT

A two-fold opportunity exists in the arid Four Corners region of the southwestern United States: (1) the Navajo Agricultural Products Industry (NAPI), a commercial farm operated by the Navajo Nation, has sizable holdings of idle rectangular fields not appropriate for convertion from side roll irrigation systems to center pivots; and (2) Western Excelsior Corporation, a nearby fiber mill, is seeking sustainable alternatives to logging native quality aspen (*Populus tremuloides*) from the nearby San Juan Forest. Recent adoption of irrigated hybrid poplar (*Populus* spp.) has created marketing possibilities previously unavailable.

In 2002 and 2003, 10 and 20 hybrid poplar clones, respectively, were planted to determine establishment, leaf chlorosis, growth, and survival on a calcareous soil under drip irrigation at the NMSU Agricultural Science Center in Farmington, New Mexico. A range of responses to local environmental and edaphic conditions has been observed. In the 2002 trial, the clone OP-367 had the greatest height (4.1 m), basal diameter (9.2 cm), DBH (4.6 cm) and wood volume (2.9 m^3 ha^{-1}) after two growing seasons. In the 2003 trial, clones 015-29, 059-289, 049-177 and OP-367 showed the greatest heights and basal diameters after a single growing season but varied in degree of leaf chlorosis as measured with a Minolta 502 SPAD meter. The clone OP-367 had low chlorosis ratings in both trials. All clones responded positively to iron chelate injected through the irrigation system. Based on our evaluations, the clone OP-367 appears to be the best candidate for local wood production.

Keywords: SPAD reading, *Populus* spp., water use

INTRODUCTION

Adoption of hybrid poplar (*Populus* spp.) production under drip irrigation in the semi-arid Four Corners region of the United States could provide a viable replacement for costly, restrictive quality aspen (*Populus tremuloides*) logging. Hybrid poplar could also provide wood for fuel, poles for traditional Navajo construction, and incentives for plantation development around coal burning power generating plants for carbon sequestration in the form of tradable carbon credits. In 2002 and 2003, two trials were initiated to evaluate hybrid poplar establishment at the New Mexico State University Agricultural Science Center at Farmington. Early results have

generated interest between the Navajo Agricultural Products Industry (NAPI), a 26,000-ha commercial farm operated by the Navajo Nation, and Western Excelsior Corporation (Mancos, CO), a nearby fiber mill. A joint venture could create unique possibilities by diversifying NAPI's production while supplying a sustainable source of timber to Western Excelsior. Objectives of this project were to identify hybrid poplar clones suitable for the high pH, calcareous soils inherent in the region and determine water use requirements and growth rates.

MATERIALS AND METHODS
2002-Planted Poplar

Ten hybrid poplar clones were obtained from commercial nurseries (Table 1) for planting on a Doak sandy loam (fine-loamy, mixed, mesic Typic Haplargid) (Keetch 1980). Water-holding capacity in the 0.9-m profile is 12.6 cm (14 cm m^{-1}) and pH averages 8.2. Prior to planting, the 0.6 ha field was disked, leveled, and 1.59 L hr^{-1} Netafim surface drip tubing (emitters spaced every 0.9 m) was installed (2 dripper lines per row of trees). On May 15, 16 cuttings per clone were planted on a 3 x 3 m spacing in three replicated blocks. Cuttings that failed to grow were replaced with greenhouse transplants as needed throughout 2002. Monthly water-use rates derived by Gochis and Cuenca (2000) were used to generate daily evapotranspiration (ET) estimates for scheduling irrigations.

Table 1. Parentage of 10 hybrid poplar clones planted May 2002 and grown under drip irrigation; NMSU Agricultural Science Center at Farmington, NM.

Entry	Female Parent	Source	Male Parent	Source
Eridano	*P. deltoides*	France	*P. maximowiczii*	Japan
NM-6	*P. nigra*	Unknown	*P. maximowiczii*	Unknown
OP-367	*P. deltoides*	Unknown	*P. nigra*	Unknown
49-177	*P. trichocarpa*	Orting, WA	*P. deltoides*	Texas
50-194	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 005)
52-225	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 101)
58-280	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 129)
184-411	*P. trichocarpa*	Randle, WA	*P. deltoides*	Oklahoma (17-10)
195-529	*P. trichocarpa*	Old plantation in WA	*P. deltoides*	Oklahoma (21-7)
311-93	*P. trichocarpa*	Nisqually River, WA	*P. nigra*	Loire Valley, France

Leaf chlorosis ranking on a scale of 1-5 (5 being the most chlorotic) was determined for all trees on August 31 and September 16, 2002. A Minolta SPAD 502 (Soil Plant Analysis Development) chlorophyll meter was used to obtain indicators of leaf chlorosis on July 1, August 19, and September 15, 2003. The SPAD meter measures leaf light transmittance at 650 and 940 nm wavelengths to estimate chlorophyll content (Schepers et al. 1998). Readings in the 50's indicate deep green color (Loh et al. 2002) while decreasing values indicate chlorosis. One leaf from the east side of all 16 trees per plot was used to average SPAD readings for each of 10 entries in each replication.

First year final survival, tree height, and basal diameter were determined December 18, 2002. Second year survival, height, basal diameter and diameter at breast height (DBH) at 137 cm were determined in December 2003. Wood volume was calculated after Browne (1962) and adjusted to cubic meters per hectare.

2003-Planted Poplar

In May 2003, 20 clones (Table 2) were planted on a site having similar soil characteristics as those mentioned above. Cultivation and planting followed similar methodology with the exception of the spacing at 1.5 x 1.5 m and that only a single line of surface drip tubing (1.59 L hr^{-1} Netafim) was used per row of trees. Leaf chlorosis evaluations using the SPAD 502 meter were made during a single evaluation in September. Tree heights, basal diameter, and final survival evaluations were made in December.

Table 2. Parentage of 20 hybrid poplar clones planted May 2003 and grown under drip irrigation; NMSU Agricultural Science Center at Farmington, NM.

Entry	Female parent	Source	Male parent	Source
15-29	*P. trichocarpa*	Chilliwack, Canada	*P. deltoides*	Mississippi (ST 1)
49-177	*P. trichocarpa*	Orting, WA	*P. deltoides*	Texas (Tex S7C1)
50-184	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 005)
50-197	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 005)
52-225	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 101)
55-260	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Texas (Tex S7C1)
56-273	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 101)
57-276	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Missouri (243)
58-280	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 129)
59-289	*P. trichocarpa*	Granite Falls, WA	*P. deltoides*	Illinois (ILL 101)
184-401	*P. trichocarpa*	Randle, WA	*P. deltoides*	Oklahoma (17-10)
184-411	*P. trichocarpa*	Randle, WA	*P. deltoides*	Oklahoma (17-10)
195-529	*P. trichocarpa*	Grays County, WA	*P. deltoides*	Oklahoma (21-7)
309-74	*P. trichocarpa*	Nisqually River, WA	*P. nigra*	Loire Valley, France
311-93	*P. trichocarpa*	Nisqually River, WA	*P. nigra*	Loire Valley, France
DN-34	*P. deltoides*	Unknown	*P. nigra*	Unknown
DTAC-7	*P. trichocarpa*	Unknown	*P. deltoides*	Unknown
Eridano	*P. deltoides*	France	*P. maximowiczii*	Japan
NM-6	*P. nigra*	Unknown	*P. maximowiczii*	Unknown
OP-367	*P. deltoides*	Unknown	*P. nigra*	Unknown

The experimental design was a CRBD (20 clones with 6 cuttings per plot randomized in each of 4 blocks). Statistical analysis for both trials was facilitated in SAS 9.1.3 using PROC GLM and PROC CORR commands for means separation (Fishers Protected LSD) and correlation analysis, respectively.

RESULTS
2002-Planted Poplar

Calculations for ET replacement requirements started on May 1, 2002, and totaled 447 mm. Total water applied (including rainfall) during the first year was 551 mm (Figure 1).

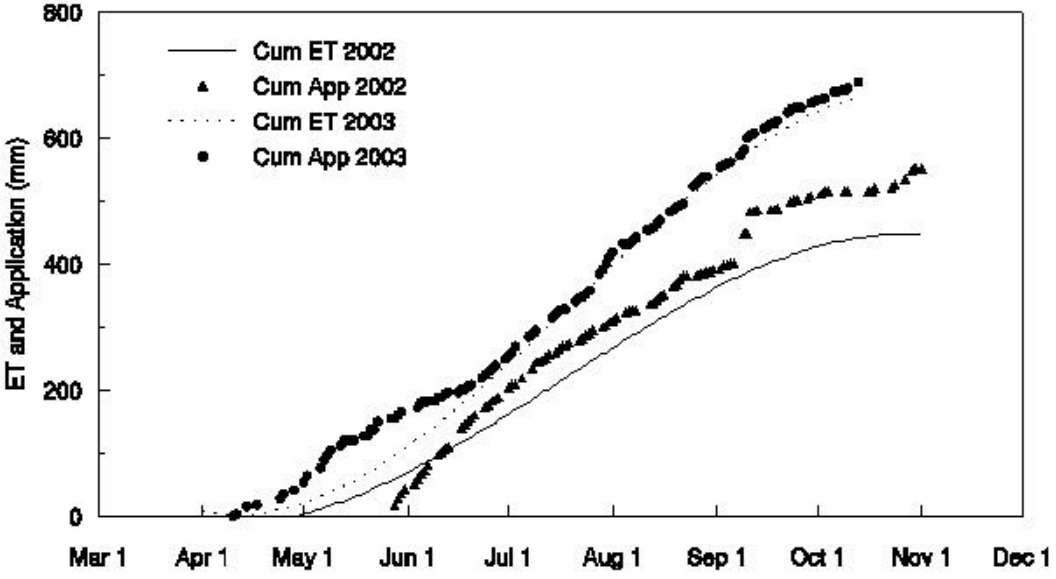

Figure 1. Cumulative evapotranspiration (mm) and cumulative water application (mm) for hybrid poplar clones grown under drip irrigation; NMSU Agricultural Science Center at Farmington, NM, 2002-2003.

Leaf chlorosis appeared on the leaves of most clones midway through the growing season. Using a visual ranking, the clone NM-6 was the most chlorotic on September 2002 with a rating of 3.4 (scale 1-5) (Table 3). The least chlorotic clones were 58-280 and OP-367 with ratings of 1.1 and 1.2, respectively.

Mean tree heights ranged from 0.87 to 1.6 m for NM-6 and OP-367, respectively (Table 3). Similarly, mean basal diameters ranged from 11.7 to 24.9 mm for NM-6 and OP-367 , respectively (Table 3). Both height and basal diameters for the 2002 growing season were highly inversely correlated with the August 31 leaf chlorosis ranking ($r = -0.67$ and $r = -0.68$, respectively) (data not shown).

The clones 50-194, 184-411, and Eridano required the greatest number of replants while OP-367 required the least (Table 3). Cones 50-194 and 184-411 had significantly lower final survival rates in December (including transplanted replacements) than the other clones (Table 3). These two clones were not continued in subsequent evaluations.

Water applications for the second year were started on April 11, 2003. Cumulative water application plus rainfall totaled 688 mm; slightly more than the calculated cumulative ET replacement value of 665 mm (Figure 1).

Table 3. First season growth characteristics for 10 hybrid poplar clones planted May 2002 and grown under drip irrigation; NMSU Agricultural Science Center at Farmington, NM.

Entry	Chlorosis Aug 31 (1-5)[a]	Chlorosis Sept 16 (1-5)	Height (m)	Basal Diameter (mm)	Replants Required (No.)	Final Survival (%)
OP-367	1.5 d[c]	1.2 b	1.65 a	24.9 a	2.0	100.0
311-93	2.4 c	1.9 ab	1.34 b	21.9 bc	4.7	100.0
58-280	2.2 c	1.1 b	1.15 c	22.6 ab	3.7	97.9
49-177	3.1 b	2.3 ab	1.14 c	20.0 c	4.7	100.0
184-411	2.8 b	2.3 ab	1.05 cd	20.3 bc	9.3	70.8
Eridano	3.1 ab	3.1 a	0.98 de	13.9 ef	8.0	97.9
50-194	2.9 b	2.7 ab	0.96 de	16.6 d	10.3	72.9
195-529	3.4 a	3.0 a	0.91 de	15.3 de	5.0	100.0
52-225	2.8 b	2.9 a	0.88 e	14.4 ed	2.3	100.0
NM-6	3.5 a	3.4 a	0.87 e	11.7 f	2.7	100.0
Mean[b]	2.8	2.4	1.10	18.1	5.3	94.0
P	<0.0001	0.1007	<0.0001	<0.0001	<0.0001	<0.0001
CV (%)	30.3	40.8	32.8	34.5	31.1	22.7
LSD (0.05)	0.35	1.67	0.15	2.61	2.81	8.5

[a]Chlorosis rating from 1 to 5 with 5 being the most chlorotic.
[b]Mean is calculated from 3 replications with 16 trees for each plot.
[c]Means followed by the same letter within a column are not significantly different from each other at the 0.05 level.

Leaf chlorosis was again evident and chelated iron was foliar applied on June 4, 2003. Chlorosis evaluations on July 1 with the SPAD 502 meter indicated that OP-367 had the highest reading (lowest chlorosis) of 42.5 (Table 4). Iron chelate was injected into the irrigation line on July 18 and July 25. August 19 SPAD readings increased for all clones and a final evaluation on September 15 again indicated that OP-367 had the highest SPAD reading at 50.3 while 52-225, 195-529, and Eridano exhibited the lowest readings (highest chlorosis) (Table 4). Clones having the lowest SPAD values in July (Eridano, NM-6, and 195-529) responded the greatest to chelated Fe applications by increasing their average SPAD reading 30% (Table 4).

Mean tree heights in December 2003 ranged from 2.3 m for Eridano to 4.1 m for OP-367 (Table 4). Mean DBH ranged from 14.7 to 46.4 mm for NM-6 and OP-367, respectively. Mean wood volume also followed this pattern ranging from 0.33 to 2.86 m^3 ha^{-1} for NM-6 and OP-367, respectively. There were no significant differences between the eight clones for percent survival after the second year (Table 4). Leaf chlorosis was inversely correlated with height, DBH, and wood volume. The SPAD readings were positively correlated with height ($r = 0.65$, $P<0.0001$), DBH ($r = 0.58$, $P<0.0001$), and wood volume ($r = 0.50$, $P<0.0001$) (data not shown).

2003-Planted Poplar

December 2003 mean tree heights ranged from 1.0 m for 55-260 to 1.8 m for 15-29 (Table 5). OP-367 had a height of 1.6 m, not significantly different from 15-29. Mean basal diameters ranged from 12.6 mm for Eridano to 29.4 mm for 49-177. Clones OP-367 and DN-34 had diameters of 23.9 mm and 23.8 mm, respectively.

Table 4. Second season growth characteristics for 8 hybrid poplar clones planted May 2002 and grown under drip irrigation; NMSU Agricultural Science Center at Farmington, NM.

Entry	SPAD-1 7/1/03 (No.)	SPAD-2 8/19/03 (No.)	SPAD-3 9/15/03 (No.)	Height (m)	Basal Diameter (mm)	DBH[a] (mm)	Wood Volume (m^3/ha)	Final Survival (%)
OP-367	42.5 a[c]	50.7 a	50.3 a	4.1 a	91.7 a	46.4 a	2.86 a	100.0
311-93	37.0 b	37.8 cd	37.4 cd	3.5 b	71.8 b	29.2 bc	1.12 b	100.0
58-280	32.5 c	41.4 b	42.6 b	3.2 bc	71.9 b	32.2 b	1.17 b	98.0
49-177	32.6 bc	42.0 b	39.4 bc	3.1 cd	64.5 b	27.2 c	0.92 bc	100.0
195-529	23.1 de	34.0 d	39.3 bc	3.0 d	55.5 c	21.6 d	0.61 cd	97.9
52-225	26.6 d	34.7 de	35.0 de	2.7 e	54.1 cd	21.3 d	0.62 cd	95.8
NM-6	23.7 de	40.8 bc	39.5 bc	2.5 ef	43.2 e	14.7 e	0.33 d	100.0
Eridano	21.2 e	33.1 e	33.1 e	2.3 f	47.1 de	20.7 d	0.64 cd	95.8
Mean[b]	29.9	39.4	39.6	3.1	62.6	25.7	1.06	94.0
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.4929
CV (%)	36.9	20.8	23.3	24.7	30.7	41.7	84.6	12.6
LSD (0.05)	4.46	3.31	3.74	0.31	7.77	4.72	0.38	50.0

[a]DBH = Diameter at breast height (137 cm).
[b]Mean is calculated from 3 replications with16 trees for each plot.
[c]Means followed by the same letter within a column are not significantly different from each other at the 0.05 level.

Table 5. First season growth characteristics for 20 hybrid poplar clones planted May 2003 and grown under drip irrigation; NMSU Agricultural Science Center at Farmington, NM.

Entry	SPAD[a]	Height (m)	Basal Diameter (mm)	Final Survival (%)
15-29	26.4 cdefg[c]	1.8 a	25.0 b	75
59-289	36.3 b	1.7 ab	25.8 ab	92
OP-367	52.2 a	1.6 abc	23.9 bc	92
49-177	31.1 c	1.5 bcd	29.4 a	88
311-93	31 cd	1.4 bcde	20.6 cde	100
58-280	25.9 efgh	1.4 cde	23.1 bcd	83
57-276	27.3 cdef	1.4 def	20.0 def	96
50-197	20.3 i	1.4 defg	22.5 bcd	79
309-74	15.5 j	1.4 defg	14.3 ij	96
195-529	20.9 i	1.3 defg	18.1 efgh	92
DN-34	51.3 a	1.3 defg	23.8 bc	100
184-401	22.3 ghi	1.3 defg	20.7 cde	92
184-411	21.4 hi	1.3 efgh	19.8 defg	58
52-225	26.4 defg	1.3 efgh	19.4 defgh	92
NM-6	30.2 cde	1.3 efgh	13.6 ij	79
56-273	23.6 fghi	1.2 fghi	16.9 fghi	96
DTAC-7	22.7 fghi	1.2 ghij	16.0 hij	100
Eridano	20.3 i	1.1 hij	12.6 j	71
50-184	30.7 cd	1.0 ij	16.2 ghij	88
55-260	13.7 j	1.0 j	13.7 ij	92
Mean[b]	27.8	1.3	19.8	88
P	<0.0001	<0.0001	<0.0001	<0.0001
CV (%)	27.7	27.1	30.5	34.4
LSD (0.05)	4.7	0.2	3.7	17.2

[a]As values decrease, chlorosis increases.
[b]Mean is calculated from 4 replications with 6 trees for each plot.
[c]Means followed by the same letter within a column are not significantly different from each other at the 0.05 level.

The SPAD 502 meter indicated that the clones OP-367 and DN-34 had the darkest green color at 52.2 and 51.3, respectively (Table 5). Clones exhibiting the highest degree of chlorosis were 55-260, 309-74, and Eridano with values of 13.7, 15.5, and 20.3, respectively. First year survival ranged from 58% for 184-411 to 100% for the clones 311-93, DN-34, and DTAC-7, respectively.

DISCUSSION

Climatic conditions were more severe in Farmington (O'Neill et al. 2003) than at poplar research sites in Malheur, Oregon (Shock et al. 2002). Total annual precipitation was less (195 and 158 mm in 2002 and 2003, respectively), total pan ET was greater (1933 and 1913 mm, respectively, for 2002 and 2003), and mean cumulative Growing Degree Days (base = 10^{o}C) were greater (2,973 and 3,045 during 2002 and 2003, respectively) at Farmington than at Malheur (O'Neill et al. 2003; Shock et al. 2002). Higher GDD as Farmington suggests the possibility of yield potential that has not been realized. Irrigation applications derived from Boardman, OR (Gochis and Cuenca 2000) may have underestimated ET at Farmington (O'Neill et al. 2003) affecting biomass growth (Shock et al. 2002). Additionally, Timmer (1985) found that a pH between 6 and 7 was optimum for the growth of a single poplar clone. Leavengood et al. (2001) attributed height reduction by 73% of OP-367 to increased soil pH from 7.7 to 8.5. The pH of the soil used in this trial was 8.2.

Iron is thought to play a role in the formation of leaf thylakoid membrane with deficiency symptoms exhibited as a decrease in pigments and chlorosis (Abadía and Abadía 1993). Elevated soil pH reduces the availability of iron, while chelation renders iron more available (Brady 1984).

Johnson and Johnson (2003) suggest that hybrid poplar breeding programs for semi-arid regions should include *P. nigra*, as one of the parents. In these trials, the clones NM-6, OP-367, 309-74, and 311-91 all had *P. nigra* parentage, although NM-6 was developed from a female *P. nigra* parent while OP-367 and 311-93 were derived from male *P. nigra* parents. Only OP-367 and DN-34 (both exhibiting low chlorosis) had *P. deltoids* as the female parent suggesting that this species could also be important in conferring adaptation to high pH soils.

CONCLUSION

The clone OP-367 was the tallest entry, had superior basal diameters, and DBH after two seasons for the 2002 trial. The next tallest entry, 311-93, produced only 39% of the wood volume obtained by OP-367. For the 2003 trial, clones 15-29 and 59-289 had statistically the same height and basal diameter measurements as OP-367 but were more susceptible to leaf chlorosis than OP-367. Although not as tall as 15-29, 59-289, and OP-367, the clone DN-34 had chlorophyll content similar to OP-360. The equations extrapolated from Boardman, OR seemed to underestimate water requirements in Farmington as OP-367 produced more biomass in Boardman and Malheur, OR. Further research is required to quantify water use and micronutrient requirements.

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