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Effects of polyethylene mulch in a short-rotation, poplar plantation vary with weed-control strategies, site quality and clone

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Abstract

The utility of mulching in various forestry applications remains unclear due to mixed results in field trials. Additionally, few studies have attempted to assess the utility of mulching across a range of conditions, to determine the circumstances that maximize the degree and longevity of mulching-related enhancements. The objective of this study was to gauge the effect of black polyethylene mulch (poly mulch) across a range of site conditions, weed-control treatments and genotypes in a short-rotation, poplar plantation, to describe the circumstances that maximize the benefits of mulching on early growth and survival. Poplar plantations composed of one native clone (*Populus deltoides* Bartr. [D105]) and one hybrid clone (*P. nigra* L. × *P. maximowiczii* A. Henry [NM6]) were established in a randomized complete-block design (2.4 m × 3 m spacing) during May, 1999, under intensive and minimal weed-control strategies at two sites of different soil quality. Nested within each weed-control treatment was an assessment of tree performance using poly mulch vs. no mulch. Stem volume increments (SVI, dm^3) were measured on trees in all treatments during the 1999 and 2000 growing seasons. During establishment (1999), poly mulch enhanced SVI in all treatment combinations. In the second year, the benefit of mulching was restricted to conditions of higher vegetative competition and lower site quality. The relative benefit of poly mulch (i.e., the ratio of SVI under mulched vs. non-mulched conditions) increased in the second year in conditions of high vegetative competition at both sites, while it decreased in the intensively managed plots at both the sites. Tree survival exceeded 90% for both the clones in all treatment combinations, except under the greatest vegetative competition (i.e., high-quality site with minimal weed control), where survival for D105 fell below 40% in both mulched and non-mulched conditions. While poly mulch may improve early growth in short-rotation, woody crop plantations under a wide range of conditions, its practical utility appears to be restricted to specific applications. At the high-quality site in this study, mulching showed little potential as an economically feasible tool under either intensive weed control (due to the rapid attrition of mulching benefits) or minimal weed control (due to low survival and slow growth). Conversely, on marginal sites poly mulch may provide a more attractive management option in both intensive and minimal weed-control applications, particularly for certain clones.

Keywords: Polyethylene mulch; Woody crops; Weed control

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1. Introduction

For centuries, mulching has been recognized as a beneficial practice in agronomic systems (Waggoner et al., 1960; Robinson, 1988; McDonald and Helgerson, 1990; Adams, 1997), where it often enhances growth and yield of annual and perennial crops (e.g., Rowe-Dutton, 1957; Bowersox and Ward, 1969; Davison and Bailey, 1979; Robinson, 1988; Truax and Gagnon, 1993; Tarara, 2000). This enhancement has been attributed to the reduction of vegetative competition in the rooting zone (Ricotta and Masiunas, 1991; Davis, 1994; Adams, 1997) and increases in the availability of key soil resources such as nitrogen (Clarkson, 1960; Walker and McLaughlin, 1989; Truax and Gagnon, 1993; Wien et al., 1993) and water (DeByle, 1969; Flint and Childs, 1987; McDonald and Helgerson, 1990; Truax and Gagnon, 1993; McDonald et al., 1994). Mulching has also been shown to accelerate early root growth and nutrient uptake (Waggoner et al., 1960; Robinson, 1988; McDonald and Helgerson, 1990; Wien et al., 1993).

More recently, the utility of mulching (e.g., plastic or wood-fiber sheeting) has been assessed in various forestry applications (Wakeley, 1954; Walker and McLaughlin, 1989; McDonald and Helgerson, 1990; McDonald et al., 1994), including the establishment of hardwood and conifer plantations (Truax and Gagnon, 1993; McDonald and Helgerson, 1990), short-rotation, woody crop plantations (Walker and McLaughlin, 1989; Adams, 1997), and in reforestation efforts following intensive logging in western and northern forests (Flint and Childs, 1987; McDonald and Helgerson, 1990; Houle and Babeux, 1994; McDonald et al., 1994). The success of such applications depends on improvements in survival and early growth, and it is assumed that mulching should enhance both factors (Davies, 1988a; Walker and McLaughlin, 1989; Adams, 1997; McDonald et al., 1994). However, results from mulching studies in forestry applications have been mixed (Adams, 1997), with beneficial effects in certain cases (e.g., Jobling, 1960; Loewenstein and Pitkin, 1970; Carpenter et al., 1978; Parfitt and Stott, 1984) and not in others (e.g., Reitveld and Heidmann, 1974; Town and Graham, 1982; Flint and Childs, 1987; Davies, 1988a; McDonald and Helgerson, 1990; Houle and Babeux, 1994).

To assess the potential utility of mulching in forestry applications, it is vital to determine the conditions under which the greatest and most persistent benefits can be realized (Davies, 1988a; Robinson, 1988). Some studies have suggested that mulching should confer a larger benefit in forestry applications on poorer sites (Davies, 1988b; McDonald and Helgerson, 1990), under conditions of greater vegetative competition (Davies, 1988b; Adams, 1997), and for genotypes poorly suited to site conditions (Hermann, 1967; McDonald and Helgerson, 1990). But, few studies have attempted to assess the utility of mulching across a range of conditions, to determine the circumstances that maximize the degree and longevity of mulching-related enhancements.

Thus, the objective of the present study was to gauge the effect of mulching on early tree growth and survival under different site conditions and cultural treatments in a short-rotation, poplar plantation, using two genotypes thought to differ in early rooting characteristics. As short-rotation, woody crop systems often require high inputs of pesticides and fertilizers as well as repeated mechanical cultivation (Braunstein et al., 1981; Burns and Honkala, 1990; Hansen et al., 1993); mulching may offer a particularly effective management alternative to reduce both costs and environmental impacts (Jobling, 1960; Bowersox and Ward, 1969; Parfitt and Stott, 1984; Truax and Gagnon, 1993; Kling, 1995). We hypothesized that mulching would confer a growth benefit under all study conditions during establishment, but that the relative benefit of mulching would increase with the level of competing vegetation, with decreasing site quality, and in the genotype with poor early rooting. Additionally, we hypothesized that the growth benefit realized from mulching would diminish more quickly under better growing conditions (e.g., higher soil quality and lower competition).

2. Methods and materials

2.1. Study design and site conditions

At the University of Wisconsin Arlington Research Farms (Arlington, WI, USA, 43°20′17″N; 89°22′-49″W), poplar plantations were established in May, 1999 (Burns and Honkala, 1990, pp. 577–582; Green et al., 2001) under each of two weed-control strategies at two sites of different soil quality. Nested within each weed-control strategy was an assessment of tree performance with and without black polyethylene mulch. While many types of mulch have been examined, black polyethylene sheeting ("poly mulch") has become the most commonly used material because of specific thermal and optical properties considered to be particularly beneficial (Waggoner et al., 1960; Smith et al., 1968; Bowersox and Ward, 1969; Flint and Childs, 1987; Walker and McLaughlin, 1989; Tarara, 2000). Monoculture stands were planted using dormant, unrooted stem cuttings and arranged in a randomized complete-block design. Precipitation during the period of greatest growth (June 1 through August 31) was above the 30-year average (281.9 mm, Midwestern Climate Center, 2000) in both 1999 and 2000 (330.5 and 416.5 mm, respectively).

Stands of two poplar genotypes (one native to Wisconsin and one hybrid) were established to assess interactions between poly mulch and early rooting capacity. The native genotype (D105) was a clone of *Populus deltoides* Bartr. thought to exhibit poor early rooting (Dickmann and Stuart, 1983; Burns and Honkala, 1990, pp. 577–582). The second genotype was an interspecific hybrid (NM6, [*P. nigra* L. × *P. maximowiczii* A. Henry]) thought to display exceptional early rooting that has been observed in both parents (Dickmann and Stuart, 1983; Stettler et al., 1996).[1]

To examine interactions between poly mulch and site conditions, we selected two locations of high and low edaphic quality. Soil on the high-quality site was a low-lying Huntsville silt loam (Cumulic Hapludoll) with an A horizon thickness of approximately 1 m (Hole, 1976). Organic matter content in the upper 30 cm soil profile based on sample combustion was 6.74 ± 0.22%. A lower-quality site was located on a well-drained glacial drumlin, where the soil was classified as a Ringwood silt-loam (Typic Argiudoll) with an A horizon thickness of approximately 15 cm (Hole, 1976). Organic matter content of soil samples from the lower-quality site was 3.08 ± 0.10%. Finally, to assess interactions between poly mulch and vegetative competition, both intensive (conventional till/herbicide) and minimal weed-control strategies were implemented at each site.

2.2. Site preparation, treatment establishment and maintenance protocols

In mid-May, 1999, spraying of all living vegetation with glyphosate (Monsanto, St. Louis, MO) was followed by soil disking to a depth of 15 cm for both intensive (conventional till/herbicide) and minimal weed-control treatments. Soil clods were broken up using a spring harrow and culta-mulcher to provide a more level surface for the poly sheeting. For the intensive treatment, a pre-emergent herbicide (Squadron, BASF, Research Triangle Park, NC) was then applied at a rate of 2.84 l/acre to inhibit weed germination through the growing season.

Davies (1988b) found that the benefit of black poly mulch was correlated to the patch size of the sheet, and he recommended a minimum size of 1 m^2 for optimal results. Consequently, 1 m wide strips of 40 μm black polyethylene sheeting were installed over randomized halves of each treatment row (3 m spacing) using a disc-trencher, which buried the edges of the sheets to a depth of 10 cm. This procedure was intended to extend the useful life of the poly mulch by minimizing wind-related damage observed by others in applications where poly sheets were surface mounted (McDonald and Helgerson, 1990) and to create a physical barrier that reduced the incursion of vegetative roots from outside.

Dormant 20 cm stem cuttings of each genotype were then planted in treatment rows at a 2.4 m spacing in late May, 1999. Surrounding each plot, a one-row buffer strip of the same genotype was planted to minimize edge effects between treatments.

In the minimal weed-control treatment, glyphosate was applied with a backpack sprayer in a 0.25 m radius around individual trees (where plastic mulch was absent) once in early June to control early weed

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[1] Ancillary data (Green et al., unpublished) is consistent with the assumption that D105 displays poor early rooting and NM6 expresses exceptional rooting. In a study to examine early rooting differences between D105 and NM6, ratios between root mass and leaf area (*R*/*L*, g m^{-2}) were compared in pot-grown cuttings. *R*/*L* ratios should reflect whole-plant balance between the water supply capacity of the root system and the water demand of the photosynthetic surface, with higher values indicating a more favorable condition. Six weeks after planting, *R*/*L* ratios were significantly greater in NM6 (D105, 3.6 ± 0.32; NM6, 5.4 ± 0.45; $P = 0.01$).

Table 1
Implementation costs (in dollars per hectare) for weed-control treatments with and without plastic mulching for 1999 and 2000 and for years combined[a]

Cost component	1999		2000		Combined	
	Intensive	Minimal	Intensive	Minimal	Intensive	Minimal
Tillage	56.10	56.10	0	0	56.10	56.10
Cuttings	299.75	299.75	0	0	299.75	299.75
Planting	59.40	59.40	0	0	59.40	59.40
Herbicide	281.62	5.50	281.62	0	563.24	5.50
Total cost (without mulch)	696.87	420.75	281.62	0	978.49	420.75
Plastic sheeting	287.50	287.50	0	0	287.50	287.50
Plastic application	35.20	35.20	0	0	35.20	35.02
Total cost (with mulch)	1019.57	743.45	281.62	0	1301.19	743.45

[a] Tillage costs include primary tilling and two additional passes with a spring harrow. Cutting costs are based on local market prices at the time of study establishment ($0.25 per cutting). Planting costs are based upon estimates of manual planting at a rate of $9.00 per person hour. Herbicide costs for bare soil include early season application of pre-emergent chemical and subsequent application of glyphosate during the growing season. Herbicide costs for minimal weed control include spot application of glyphosate following planting. Plastic sheeting costs are based on a quoted price of $0.03 per linear foot.

growth. During the second half of the growing season, glyphosate was spot-applied (with a backpack sprayer) for control of weeds on two occasions in the intensive treatment. In 2000, the intensive weed-control treatment received the same pre-emergent herbicide application and periodic glyphosate spot-spraying throughout the growing season. The minimal weed-control plots received no additional treatment in 2000.

Costs associated with site preparation (Table 1) were calculated based on information provided by the Arlington Research Farms Operations Director. Other costs (i.e., herbicide, plastic sheeting, poplar cuttings) were calculated based on local market prices for each item at the time of implementation.

2.3. Growth measurements

Stem heights and basal diameters (at 10 cm above soil) were measured on all trees at the end of the growing seasons in 1999 and 2000. In addition, growth measurements were conducted on half of the trees in each plot at the end of each month throughout the growing season in 1999 and 2000 to assess seasonal trends. Stem measurements were used to estimate annual and monthly stem volume increment (SVI), (dm^3) for individual trees using the equation: stem volume $= 1/3(\pi r^2 h)$, where r is the stem basal radius and h the stem height. In the minimal weed-control treatment, we also estimated the average height of vegetation in close proximity to each tree in late July at both sites in 1999 and 2000 to help elucidate interactions between groundcover competition and poly mulching. For each tree, the height of the nearest plant was measured in six compass directions (45°, 90°, 135°, 225°, 270°, and 315°). To assess the influence of poly mulch on survival in all treatment combinations, we tallied all the dead trees in mid-September in 1999 and 2000.

2.4. Statistical analysis

The mixed models procedure (PROC MIXED) in SAS (SAS, 2000) was used to test the significance of differences in means ($\alpha = 0.05$) for SVIs, the ratios of SVI in mulched to non-mulched conditions ($SVI_{mulched/SVInon-mulched}$), the ratios of weed height to tree height (W/T), and tree survival at the end of each growing season. Prior to analysis, mean survival data were transformed by taking the arcsin of the square root of percent survival (Sokal and Rohlf, 1995). The significance of site, weed-control regime, genotype and growing season effects on $SVI_{mulched}/SVI_{non-mulched}$ and percent survival were assessed using PROC MIXED, treating block as a random effect and plot (composed of 16 trees) as the experimental unit. The degrees of freedom for error in these split-plot models were adjusted to account for the pooling of unequal variances using the Satterthwaite approximation (SAS, 2000). In no case did we detect a significant block effect.

3. Results

3.1. Effect of poly mulch on average stem volume production

In 1999, poly mulch significantly increased average SVI (dm^3) in all conditions for both D105 and NM6 (Table 2). In 2000, SVI was also significantly enhanced using poly mulch in nearly all conditions at both sites. In that year, however, SVI was strongly and positively correlated with stem volume at the beginning of the growing season in all cases ($P < 0.001$). Thus, we normalized all SVI means to reflect variation in the initial tree size in 2000. Based on normalized means for SVI, the effects of mulching in 2000 among treatments and sites were mixed (Table 2). Notably, there was no detectable mulching effect in the high site quality/intensive weed-control condition (H_I) for either genotype, but a significant benefit in the low site quality/intensive weed-control condition (L_I) for both genotypes (see Table 3 for treatment codes). Conversely, poly mulch was highly beneficial in the minimal weed-control treatments at both sites, with the exception of H_L for D105.

3.2. Relative benefit of poly mulch

The ratio of SVI in the mulched treatment to SVI in the non-mulched condition ($SVI_{mulched}/SVI_{non\text{-}mulched}$) was used to assess the relative benefit of mulching (Table 4 and Fig. 1). While we observed no significant main effect of site on $SVI_{mulched}/SVI_{non\text{-}mulched}$ in the overall model, weed-control treatment was highly significant (Table 4). As there was also a highly significant interaction between weed control and year, we conducted the analysis by growing season and found that the effect of weedcover treatment was unique to 2000 (Table 5). In this case, $SVI_{mulched}/SVI_{non\text{-}mulched}$ was low in the intensive weed-control treatments at both sites and high in the minimal weed-control treatments at both sites (Fig. 1). Conversely, during the first growing season a highly significant interaction between site and weed control resulted in crossed effects between sites, and $SVI_{mulched}/SVI_{non\text{-}mulched}$ was highest in the L_I and H_M conditions and lowest in the H_I and L_M conditions (Fig. 1). The effect of genotype on $SVI_{mulched}/SVI_{non\text{-}mulched}$ was moderately significant in the overall model (Table 3), but the analysis by year revealed that clonal differences were restricted to the first growing season (Table 5).

Table 2
Means for SVI (dm^3, ±SE) in 1999 and 2000[a]

Site	Weed control	Genotype	1999 SVI		2000 SVI		2000 Normalized SVI		
			Mulch	No mulch	Mulch	No mulch	Mulch	No mulch	P
High quality	Intensive	D105	0.22 ± 0.015	0.14 ± 0.008	6.38 ± 0.175	5.54 ± 0.139	5.96	5.95	0.90
		NM6	0.36 ± 0.016	0.19 ± 0.010	4.48 ± 0.147	3.33 ± 0.125	4.56	4.44	0.22
	Minimal	D105	0.04 ± 0.005	0.01 ± 0.002	0.21 ± 0.069	0.04 ± 0.060	0.08	0.05	0.88
		NM6	0.07 ± 0.006	0.03 ± 0.003	0.51 ± 0.043	0.11 ± 0.016	0.31	0.15	0.0003
Low quality	Intensive	D105	0.12 ± 0.010	0.02 ± 0.003	4.52 ± 0.153	2.60 ± 0.140	3.82	3.32	0.01
		NM6	0.26 ± 0.017	0.11 ± 0.010	5.98 ± 0.234	4.03 ± 0.160	5.54	4.88	0.03
	Minimal	D105	0.08 ± 0.005	0.04 ± 0.004	0.89 ± 0.071	0.24 ± 0.042	0.74	0.39	<0.0001
		NM6	0.13 ± 0.007	0.08 ± 0.006	1.21 ± 0.210	0.42 ± 0.099	0.98	0.53	<0.0001

[a] In 1999, the effect of poly mulch was highly significant in all cases ($P < 0.0001$). In 2000, the effect of poly mulch was significant ($P < 0.001$) in all cases except for D105 in the high-quality site/minimal weed-control condition ($P = 0.41$). P-values indicate the significance of poly mulch effects in each condition when SVI was normalized for initial size in 2000 based on least squares means generated using PROC MIXED in SAS.

Table 3
Explanations of abbreviations used for treatment combinations. Letter order of abbreviations corresponds to the order of treatment factors in the table

Abbreviation	Site quality (H/L)	Weed control (I/M)	Mulching (±)
H_{I+}	High	Intensive	Mulch
H_{I-}	High	Intensive	No mulch
H_{M+}	High	Minimal	Mulch
H_{M-}	High	Minimal	No mulch
L_{I+}	Low	Intensive	Mulch
L_{I-}	Low	Intensive	No mulch
L_{M+}	Low	Minimal	Mulch
L_{M-}	Low	Minimal	No mulch

Table 4
Significance of site, weed-control regime, genotype and year effects on the ratio of average SVI under poly mulch to average SVI in the non-mulched condition ($SVI_{mulched}/SVI_{non\text{-}mulched}$) based on 1,31 degrees of freedom (Saitterthwaite approximation)

Source[a]	*F*-value	*P*
S	1.4	0.25
W	41.9	<0.0001
G	5.3	0.02
Y	0.2	0.65
S × W	37.2	<0.0001
S × G	3.9	0.05
S × Y	2.2	0.15
W × G	0.0	0.98
W × Y	36.2	<0.0001
G × Y	0.4	0.52
S × W × G	2.2	0.15
S × W × Y	4.3	0.05
W × G × Y	1.8	0.20
S × W × G × Y	1.4	0.27

[a] S: site, W: weed-control regime, G: genotype, Y: year.

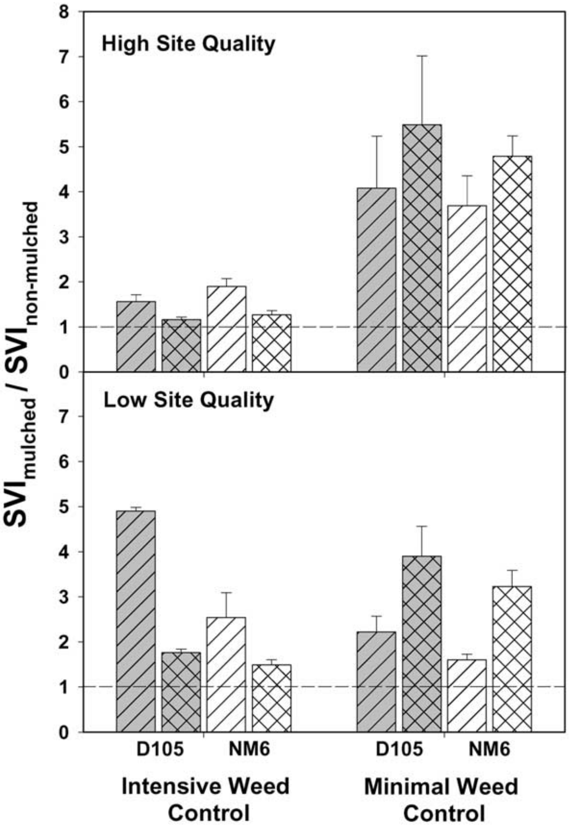

Fig. 1. Means (and S.E.) for the ratio of average SVI under poly mulch to average SVI in the non-mulched condition ($SVI_{mulched}/SVI_{non\text{-}mulched}$) for all treatment combinations in both 1999 and 2000. A value ≥ 1 indicates a benefit of poly mulch relative to no mulch. Bar pattern indicates year (hatched bars: 1999; cross-hatched bars: 2000).

Table 5
Significance of site, weed-control regime and genotype effects on the ratio of average SVI under plastic to average SVI in the non-mulched condition ($SVI_{mulched}/SVI_{non\text{-}mulched}$) for 1999 and 2000 based on 1,15 degrees of freedom (Saitterthwaite approximation)

Source[a]	1999		2000	
	F-value	*P*	*F*-value	*P*
S	0.1	0.80	2.8	0.11
W	0.1	0.72	62.9	<0.0001
G	5.5	0.03	1.1	0.31
S × W	41.9	<0.0001	6.6	0.02
S × G	7.2	0.01	0.1	0.73
W × G	1.2	0.30	0.7	0.42
S × W × G	3.5	0.08	0.2	0.70

[a] S: site, W: weed-control regime, G: genotype.

3.3. Weed-height to tree-height ratios under minimal weed control

The ratio of weed height to tree height (W/T) in late July was taken to be an index of vegetative competition in the minimal weed-control treatments in both years (Table 6). In 1999, W/T was greater than 1 (indicating that trees were overtopped by competing vegetation) in all cases, and W/T for D105 in the H_{M-} condition was significantly greater than all other treatment combinations (and it was more than twice the value of the next highest condition—H_{M-} for NM6). In 2000, W/T fell below 1 in nearly all cases. W/T was greater at the high-quality site in both 1999

Table 6
Averages for ratios of heights of competing vegetation and trees (W/T, ±SE) and tree survival (fraction, ±SE) in the minimal weed-control treatments for mulched and non-mulched conditions in 1999 and 2000[a]

Site	Genotype	Mulching condition	1999		2000	
			W/T	Survival	W/T	Survival
High quality	D105	Mulch	1.68 ± 0.11	0.69 ± 0.19	1.05 ± 0.16	0.39 ± 0.14
		No mulch	4.68 ± 0.36	0.56 ± 0.14	0.94 ± 0.13	0.19 ± 0.10
	NM6	Mulch	1.70 ± 0.03	0.94 ± 0.06	0.74 ± 0.04	0.94 ± 0.06
		No mulch	2.24 ± 0.15	0.85 ± 0.12	0.72 ± 0.13	0.81 ± 0.16
Low quality	D105	Mulch	1.12 ± 0.07	0.98 ± 0.02	0.48 ± 0.05	0.93 ± 0.07
		No mulch	1.45 ± 0.03	0.96 ± 0.02	0.60 ± 0.08	0.87 ± 0.08
	NM6	Mulch	1.04 ± 0.04	1.00 ± 0.00	0.44 ± 0.01	1.00 ± 0.00
		No mulch	1.38 ± 0.05	0.98 ± 0.02	0.48 ± 0.03	0.98 ± 0.02

[a] In both the years, survival in the intensive weed-control conditions (mulched and non-mulched) remained above 90% at both the sites for D105 and NM6 (data not shown).

and 2000 for all conditions ($P < 0.05$). Between years, W/T was greater in 1999 compared to 2000 in all cases ($P \leq 0.01$).

3.4. Effect of poly mulch on tree survival

In neither 1999 nor 2000 did percent survival differ significantly between mulched and non-mulched conditions (Table 6). In the both years, survival in the intensive weed-control conditions (mulched and non-mulched) remained above 90% at both sites for D105 and NM6 (data not shown). Survival in the minimal weed-control conditions varied between sites. In the L_M condition, survival only dropped below 90% in the non-mulched treatment for D105. Survival was markedly lower in the H_M condition for both genotypes. But, it was particularly low for D105, in which survival fell below 40% in both mulched and non-mulched conditions during the 2000 growing season. In 2000, D105 in the H_M condition had significantly lower survival than NM6 in both mulched and non-mulched treatments ($P \leq 0.02$).

4. Discussion

4.1. Effect of poly mulch on tree growth during the first two growing seasons

While the effect of poly mulch on SVI was highly significant in all cases during establishment, its relative benefit ($SVI_{mulched}/SVI_{non\text{-}mulched}$) varied considerably among treatment combinations. At the high-quality site, $SVI_{mulched}/SVI_{non\text{-}mulched}$ increased under conditions of higher competition (i.e., minimal weed control) and poor early rooting (i.e., D105), generally supporting our hypotheses. In contrast, we found interactive effects at the low-quality site for both genotypes in 1999. In particular, D105 in the L_I condition exhibited the greatest relative growth enhancement under poly mulch among all treatment combinations in 1999. In fact, during the first growing season D105 in L_{I-} was the only condition that did not exhibit significant stem volume growth during either mid- or late-season periods (late June–late July, $P = 0.35$; late July–late August, $P = 0.75$; data not shown), in spite of above-average precipitation.

Lower-quality, well-drained soils tend to have inherently lower thermal insulation (McDonald and Helgerson, 1990; Tarara, 2000), and the high radiation loads and/or surface wind velocities imposed on soils without vegetative cover (which may act as a natural mulch) may result in high evaporative water loss in shallow regions where new cuttings procure most of their moisture (Dix, 1960; Walker and McLaughlin, 1989). Indeed, ancillary data (Green et al., unpublished) indicated that on a sunny day in August, the average soil temperature measured at a depth of 7.5 cm during the photoperiod was 8.6 °C higher in the L_I condition compared to minimal weed management (28.5 °C vs. 19.9 °C, respectively; average air temperature was 27.3 °C). Additionally, average soil temperature in the L_I condition at the low-quality site was 4.5 °C higher than the same condition at the high-quality site (24.0 °C). Consequently, the particularly strong response to mulching seen in D105 under lower-quality conditions may reflect a greater vulnerability to moisture stress during establishment owing to its apparent poor early rooting habit. However, the influence of mulching on early root development may also have been vitally important in the L_I condition, particularly for D105.

In 2000, the effect of mulching on SVI (based on normalized means) was more clear at both sites, with greater responses associated with lower site quality and/or higher vegetative competition—with the exception of H_M for D105. In this case, 0% survival in the non-mulched treatment of one block reduced our statistical power to detect a mulching effect. As anticipated, the relative benefit of poly mulch in the high-intensity management conditions diminished at both sites during the second growing season, but particularly at the high-quality site. Conversely, in the minimal weed-control treatments at both sites the relative benefit of mulching increased from the 1999 levels, particularly at the low-quality site. We had expected that the greatest enhancements of mulching would have been conferred during the establishment year when both the reduction of vegetative competition and the improvement of edaphic conditions during early root development seemed particularly important. However, the effect of mulching in the minimal weed-control treatments during the first year may have been muted at both sites due to light-imposed limitations that resulted from the trees being overtopped by the cover vegetation. In 2000, tree crowns in the control plots were largely released from light limitations, and the benefits of poly mulch were probably more fully realized. Greater increases in $SVI_{mulched}/SVI_{non\text{-}mulched}$ at the low-quality site in the second year corresponded with greater release of tree crowns, further supporting the importance of light limitations in the presence of competing vegetation.

Overall, it appears that a primary benefit of poly mulch in the second growing season was the reduction of vegetative competition, and any benefit related to the improvement of edaphic environments was limited to poorer site conditions (Davies, 1988a). It is worth noting that the performance of D105 in the L_{I-} condition improved dramatically in 2000. The seasonal lags in growth for D105 in L_{I-} observed in 1999 disappeared in the second growing season (data not shown), despite only near-average precipitation during both mid- and late-season periods in 2000. These contrary findings between years suggest that D105 had developed more extensive rooting capable of tapping water sources less vulnerable to surface evaporative loss. Indeed, the lack of any clonal differences in the relative benefit of mulching in 2000 suggests a broad convergence in resource-capture capacity between D105 and NM6. Thus, poor initial rooting in a given genotype may not be a good predictor of chronic disability, and plastic may expand the pool of potential genotypes that may be selected for applications on marginal sites.

4.2. Effect of poly mulch on tree survival during the first two growing seasons

Some studies have noted increased tree survival using mulch, particularly under conditions of persistent low soil moisture (e.g., regions with "summer-dry" climates and/or thin soils; see Hermann, 1965; Bowersox and Ward, 1969; DeByle, 1969; Loewenstein and Pitkin, 1970). But, in this study, no detectable mulching effect was observed in regards to survival. The poor survival observed with and without mulching for D105 in the H_M condition suggests that low-intensity weed control on high-quality sites may be insufficient for some genotypes, even with poly mulch (although, wider strips might provide greater effectiveness under such conditions). NM6 showed a greater inherent tolerance of vegetative competition under low-intensity weed control at the high-quality site, even without poly mulch. However, given the small SVIs that we observed for NM6, it seems unlikely that even genotypes with good competitive ability could attain economically feasible growth in a short-rotation application under high site-quality conditions without intensive weed control. Overall, our findings seem to suggest that the benefits of mulching in regards to survival may be more fully expressed under conditions of low soil moisture rather than high vegetative competition.

Of special note, about 30% of the mortality for both genotypes at the higher-quality site was associated with evidence of girdling by small mammals (data not shown), but we found no indications of such damage at the lower-quality site in either 1999 or 2000. While weed cover can increase the presence of such damaging agents (Von Althen, 1983; Truax and Gagnon, 1993), a lower density of cover on marginal sites may reduce the habitat value for small mammals. And, such sites may be more conducive to plantation success under low-intensity weed control.

5. Summary

While poly mulch may improve early growth in short-rotation, woody crop plantations under a wide range of conditions, its potential economic utility appears to be restricted to specific applications. At the high-quality site in this study, mulching showed little promise as an economically feasible tool in stands under either high-intensity weed control (due to the rapid attrition of mulching benefits) or low-intensity weed control (due to high mortality and slow growth). Conversely, on marginal sites the potential utility of poly mulch appears more promising in both high- and low-intensity weed-control applications, particularly for certain genotypes. The persistent mulching effect seen under intensive weed control at the low-quality site suggests a benefit of edaphic improvement extending beyond establishment. Indeed, on well-drained, marginal sites, intensively managed plantings using genotypes with poor early rooting may not be possible without the aid of mulching. And, there may be occasions where genotypes that are inherently less suited to lower site-quality may be desirable because of other traits that may enhance long-term success (e.g., resistance to indigenous pathogens and browsers, superior stem form and strength).

The use of poly mulch in low-intensity weed control applications on marginal sites may also provide an attractive option. The impressive increase in the relative benefit of mulching in the second growing season suggests the possibility of a longer-term value. In the L_I condition, closed canopies will form early in the 2001 growing season (with and without poly mulch), and self-shading will become a limiting factor in stem volume production (Green et al., 2001). On the other hand, L_M tree crowns will remain open throughout the growing season. And, if mulching continues to provide a strong relative benefit in the minimal weed-control condition, we may see a convergence in SVI among weed-control treatments. In this case, mulching might provide a clear economic incentive.

A clear understanding of the actual economic benefits of mulching will require a longer-term assessment of growth trends. Consequently, we intend to follow growth patterns in these plantations over a longer period.

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