Effects of Site Treatments During 26 Years for Ponderosa Pine (*Pinus ponderosa* Lawson and C. Lawson [Pinaceae]) Plantings in Colorado's Northern Front Range

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Abstract

Getting tree seedlings to grow on dry, grass-covered sites in the Colorado Front Range and piedmont is a long-standing problem. We tested various planting treatments by growing ponderosa pine (*Pinus ponderosa* Lawson and C. Lawson [*Pinaceae*]) for 25 and 26 years on a mountain site and a piedmont site in Colorado's Front Range. Weed barrier, black plastic, scalping, and polyacrylamide gel applied alone or in combination proved effective at promoting seedling growth and survival compared with the untreated control treatment. Results suggest that controlling grass competition may be more important than water in regulating growth and survival of seedlings on sites where annual rainfall averages 40 cm (15 in) and summers are dry.

Introduction

Successfully planting trees in dry grassy areas has been a problem since at least 1902, when the Bureau of Forestry (later the U.S. Department of Agriculture [USDA] Forest Service) foresters established a nursery later named for Charles E. Bessey in the Nebraska Sand Hills. The Nebraska National Forest began planting in 1902 (Gardner 2009, Pool 1953). Much has been written on tree planting in the Great Plains (e.g., Baer 1989, Engle et al. 2008, Read 1964), and there are some research projects from the Colorado Rockies (Droze 1977). Less is known, however, about tree planting in the piedmont area between the mountains and the plains west of the South Platte River, particularly with scalping. This area has soils derived from mountain outwash and is often quite rocky. Down-canyon winds pile fine particles into small dunes or layers of wind-blown sand, creating extremely variable planting conditions.

Grass competition, especially from early season grasses such as smooth brome (*Bromus inermis* Leyss.) (Bond 2008, Davis et al. 1998, Goldberg and Barton 1991, Rietveld 1975), is a challenge to establishing new stands of trees in the Front Range and Great Plains. Scalping (Graham et al. 1989), plastic mulch (Green et al. 2003), wood chip mulch (Mashayekhan and Hojjati 2013), polypropylene fabric weed barrier (Geyer et al. 2006), and even carpet mulches have been tried in an effort to improve reforestation success with various species, producing variable results. Fallowing a site with plastic mulch or herbicide a year before planting tripled growth of Rocky Mountain juniper (*Juniperus scopulorum* Sarg. [*Cupressaceae*]) (Nickerson 2002). Nickerson used woven plastic weed barrier strips up to 2.3 m (7.5 ft) wide in his windbreak and living snow fence projects, covering an area of 5.57 m^2 (60 ft^2) per seedling.

The intent of mulch treatments is to form a physical barrier that prevents evaporation (thereby increasing water availability) and to starve competing plants of light (Chang-Hung 1999). Flint and Childs (1987) showed significant improvement in diameter growth of Douglas-fir (*Psuedotsuga menziesii* [Mirb.] Franco) seedlings using herbicide, scalp, and mulch treatments. Rietveld and Heidman (1974) used 45.7 cm (18-in) square plastic sheets to mulch around ponderosa pine (*Pinus ponderosa* Lawson and C. Lawson) seedlings in Arizona and remeasured seedlings annually for 3 years, terminating their experiment in the third season when seedling survival was down to 19 percent and mulch had deteriorated significantly. In the third year, seedlings mulched with polyethylene were significantly taller than those without mulch.

Water-absorbing polymers are believed to work by increasing soil water-holding capacity, increasing the size and number of pores, and mitigating soil compaction (Orzolek 1993). Callaghan et al. (1989) found that polymer treatment resulted in 57 percent survival for eucalyptus seedlings, compared with 0 percent for controls when seedlings were irrigated at 6-week intervals. Johnson and Leah (1990) found that polyacrylamide application increased mean shoot fresh weight for three species of grains up to seven times that of controls and Pryor (1988) found a 30-percent increase in tomato fruit production when polymers were applied. Polymers lose their effectiveness with time (Al-Humaid and Moftah 2006).

The objective of our study was to compare effects of a variety of planting treatments at planting time on subsequent height, diameter, and survival of southwestern ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson var. *scopulorum* Engelm.) in the Northern Front Range and piedmont. To achieve our objective, we planted two sites with southwestern ponderosa pine seedlings and tracked growth and survival annually for 6 years with later measurements at 20 and 26 years. We hypothesized that there were significant differences in height and diameter growth and survival as a result of applying a variety of treatments.

Materials and Methods

Sites

The Flagstaff site is located west of Boulder, CO, at 39°58'N, 105°20'W (figure 1) at an elevation of 2,350 m (7,710 ft) on Ferncliffe stony sandy loam (Moreland and Moreland 1975). The underlying material consists of landslide debris. Bedrock generally occurs at depths exceeding 150 cm (60 in). The planting site slopes from 2 to 16 percent southeastward. Average annual precipitation was 54 cm (21 in) between 1988 and 2009, and mainly occurred in April and May (Prism Climate Group 2016). Existing vegetation at the time of establishment consisted of southwest ponderosa pine

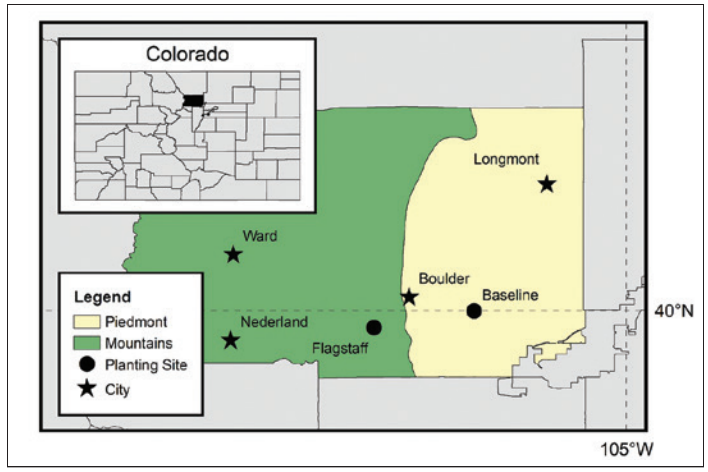


Figure 1. Experimental planting sites in Boulder County, CO. "Mountains" roughly corresponds to the "Southern Rockies Ecoregion," while "Piedmont" roughly corresponds to the "High Plains Ecoregion." Data from U.S. Environmental Protection Agency (2012).

and Douglas-fir at 4 to 8 m^2/ha (45 to 85 ft^2/acre) basal area and broadleaved plants with some short, annual, late-season (C_4) and perennial, early-season (C_3) grasses.

The Baseline site is east of Boulder, CO, at 40°00'N, 105°11'W (figure 1) at an elevation of 1,615 m (5,300 ft) on Nunn silt loam (Moreland and Moreland 1975). Bedrock is at an unknown depth greater than 150 cm (60 in). The planting site is located on a stream terrace about 4 m (15 ft) above Dry Creek in valley-fill material. Average annual precipitation is about 40 cm (16 in) (Prism Climate Group 2016). Planting site slopes about 2 percent northward. Existing vegetation at the time of planting was a heavy sod of early season (C_3) perennial grasses.

Seedlings

We used 2-year old (2+0) ponderosa pine seedlings from the Colorado State Forest Service Nursery (Fort Collins, CO). Seeds were collected west of Fort Collins, CO, and the seedlings grown in 5 by 5 by 15 cm (2 by 2 by 6 in) tarpaper pots. Seedlings were hand-planted by stripping off tarpaper and placing the seedling in a hole 17 cm (7 in) deep by 17 cm (7 in) wide. The Flagstaff site was planted in April 1990 and the Baseline site was planted in April 1991. One-month seedling viability was 97 percent or better at both sites.

Treatments and Experimental Design

A variety of treatments using polymer gel, black plastic, weed barrier, and scalping were applied with the goal of increasing soil moisture availability and decreasing competition.

The polyacrylamide gel (polymer) (Hydrogel, Plant-Best, Inc., Markham, Ontario) was mixed at the rate of one part polymer crystals to 50 parts tap water and allowed to stand overnight. In the morning, surplus water was discarded. Seedlings treated with polymer gel received either 237 ml (8 oz) or 474 ml (16 oz) of fully hydrated polymer mixed 1:1 with back-fill soil and placed around the seedling's roots to match the original soil line.

Two mulch treatments were used. The first treatment was a black plastic mulch consisting of 1.83 m (6 ft) squares of 6-ml black polyethylene plastic (Visqueen, British Polythene Ltd., Greenock, UK) with an "X" cut in the center to lessen the risk from sharp edges vibrating in the wind and cutting through the seedling. The added carbon black increases polyethylene resistance to ultraviolet light, making it last longer in sunlight. The other mulch treatment was 1.83 m (6 ft) squares of woven black plastic weed barrier (DeWitt Sunbelt, The DeWitt Company, Sikeston, MO), also with an "X" cut in the center. Weed barrier is heavier, porous, and longer lasting than black plastic. All mulch sheets were anchored to the ground with rocks, slash, or iron sod staples.

The following treatments were applied at planting time:

(1) Control (Con). Seedlings were planted without scalping, polymer, plastic, or weed barrier.

(2) Scalping (Sca). About 2.5 cm (1 in) of sod and other plant material was removed from a 1 m (3 ft) radius circle. The seedlings were planted in the center of the circle.

(3) Plastic (Pla). A black plastic square was anchored around each seedling as described previously.

(4) Polymer (Poly). Fully hydrated polymer gel (237 ml; [8 oz]) was applied as described previously.

(5) Scalping/plastic (ScaPla). Scalping and plastic treatments were combined.

(6) Scalping/polymer (ScaPoly). Scalping and polymer treatments were combined.

(7) Plastic/polymer (PlaPoly). Plastic and polymer treatments were combined.

(8) Scalping/plastic/polymer (SPP). Scalping, plastic, and polymer treatments were combined.

(9) PolymerX2 (PolyX2). Polymer gel (474 ml [16 oz]) was applied as described previously.

(10) Weed barrier (Bar). A square of landscape fabric was anchored around each seedling as described previously.

All 10 treatments were installed at the Baseline site, while only the control, plastic, and weed barrier treatments were installed at the Flagstaff site. At Baseline, 200 seedlings were planted in a randomized complete block design consisting of two blocks, with 10 seedlings assigned to each treatment per block. At Flagstaff, 90 seedlings were planted, with 30 seedlings assigned to each treatment. Many plastic sheets were blown away in a windstorm 3 days after planting. The landowner found and replaced most, but eight could not be found. These seedlings were reassigned to the control group, leaving 38 control, 22 plastic, and 30 weed barrier seedlings total.

Seedlings were measured each October from 1990 to 1997, and then measured again in 2009 and 2016. From 1990 to 1997, measurements consisted of stem diameter at 2.54 cm (1 in) above the ground, the height above the small node on the stem at the original soil line to the tip of the terminal bud, and survival. Browse by mule deer (*Odocoileus hemionus* Rafinesque) and damage to leaders by southwestern pine tip moth (*Rhyacionia neomexicana* Dyar [Lepidoptera: Olethreutidae]) were noted. In 2009 and 2016, multiple heights were measured on each tree using a clinometer and tape, starting from the top and moving down to each whorl to estimate annual heights until there were too many branches to be able to see the whorl.

Site Index Model Development

A site index equation was developed by modifying Barrett's (1978) site index model:

(1)

$$SI_i = b_1 - \left(b_2 Age_i + \frac{b_3}{Age_i}\right) b_4 \left[1 - exp\left(b_5 Age_i\right)\right]^{b6} + \left(b_7 Age_i + \frac{b_3}{Age_i}\right)(Ht_i - Ht_M) + Ht_M$$

where:

SI_i = Site index,

Age_i = Age in years (with age-at-planting = 1),

Ht_i = Measured tree height (model is applied tree-by-tree),

i = seedling index number,

Ht_M = Measurement height

b_1, b_2, b_3, b_4, b_5 and b_6 are coefficients to be estimated using PROC NLIN (SAS Institute 1985).

When equation 1 is solved for height, the result is:

(2)

$$Ht_i = \frac{(SI_i - H_M - b_1)}{\left(b_2 Age_i + \frac{b_3}{Age_i}\right)} + b_4\left[1 - exp\left(b_5 Age_i\right)\right]^{b_6} + H_M$$

To determine metric values of $b_1, b_2, b_3, b_4, b_5,$ and b_6 applicable to southwest ponderosa pine, we converted data from Minor (1964) to metric (84 observations), combined it with our data (2,420 observations), and fit equation 2. Minor's data was for sawlog-sized trees and not applicable to seedlings. We combined our dataset with Minor's so our model would be continuous with Minor's data. This produced the following values:

$b_1 = 3.5713$

$b_2 = 0.000857$

$b_3 = 91.7196$

$b_4 = 3.6808$

$b_5 = -0.0763$

$b_6 = 3.8552$

We tested these coefficients with a ten-tree sample of existing mature trees from the Flagstaff site. Using Barrett's model (equation 2), average 100-year site index was 22.6 m (74.2 ft), which agrees well with an average site index of 23.7 m (78.2 ft) obtained using the tallest 20 percent of surviving experimental seedlings at age 26.

In applying equation 2 to our data, we substituted Trt_i for SI_i where Trt_i was defined as:

(3)

$$Trt_i = b_1 Var_1 + b_2 Var_2 + \ldots + b_n Var_n$$

where:

Var_n is a dummy variable identifying a specific treatment

b_1, b_2 … bn are coefficients to be estimated.

The trajectory that the seedling follows is estimated by the values fitted to coefficients in equation 3. The value of Trt_i can be estimated for individual trees or for an entire treatment class ($p < 0.0001$, $s = 0.620$):

	Mountain:	Piedmont:
Control:	b_1 = 9.7110a	b_1 = 8.6111a
Scalp:	No data	b_2 = 10.0393ab
Plastic:	b_3 = 9.5612a	b_3 = 9.6676abc
Polymer:	No data	b_4 = 5.0050abcd
ScaPla:	No data	b_5 = 11.3921bce
ScaPoly:	No data	b_6 = 5.9321df
PlaPoly:	No data	b_7 = 10.4092beg
SPP:	No data	b_8 = 11.5255begh
PolyX2:	No data	b_9 = 6.7869abdf
Barrier:	b_{10} = 11.2333	b_{10} = 12.7536ch

Values followed by the same lowercase characters indicate identical statistical values.

We found a simple straight line equation using seedling height worked well to predict diameter:

(4)

$$Dia_i = b_0 + (b_1 Var_1 + b_2 Var_2 + \ldots + b_n Var_n) Ht_i$$

where:

Dia_i is diameter at 2.54 cm (1 in) above groundline

Ht_i is seedling height

Var_i is a dummy variable identifying a specific treatment

b_1, b_2, … , bn are coefficients to be estimated, similar to Trt_i above:

	Mountain:	Piedmont:
Constant:	Not significant	b_0 = -0.0854
Control:	b_1 = 3.3184	b_1 = 3.4704a
Scalp:	No data	b_2 = 4.8217acd
Plastic:	b_3 = 3.9484	b_3 = 4.5606ab
Polymer:	No data	b_4 = 4.5086abc
ScaPla:	No data	b_5 = 4.9236acd
ScaPoly:	No data	b_6 = 6.9273
PlaPoly:	No data	b_7 = 4.9167acd
SPP:	No data	b_8 = 4.7269acde
PolyX2:	No data	b_9 = 4.6951abcde
Barrier:	b_{10} = 3.2535	b_{10} = 4.1638c

Values followed by the same lowercase characters indicate identical statistical values.

Survival was modelled using a logarithmic decay curve:

(5)

$$S = b_0 b_1^{\,t}$$

where:

S is the proportion of seedlings still alive in Year t.

t is the planting age in years (seedlings were 2 years old when planted),

b_1, are coefficients to be estimated:

	Mountain:	Piedmont:
Control:	b_0 = 0.927; b_1 = 0.979a	b_0 = 0.982a; b_1 = 0.952a
Scalp:	No data	b_0 = 0.976b; b_1 = 0.986b
Plastic:	b_0 = 0.975; b_1 = 0.988ab	b_0 = 0.976b; b_1 = 0.999b
Polymer:	No data	b_0 = 0.992a; b_1 = 0.959a
ScaPla:	No data	b_0 = 0.941c; b_1 = 0.992b
ScaPoly:	No data	b_0 = 0.927; b_1 = 0.986b
PlaPoly:	No data	b_0 = 0.976b; b_1 = 0.989b
SPP:	No data	b_0 = 0.943c; b_1 = 0.995b
PolyX2:	No data	b_0 = 0.893; b_1 = 0.959a
Barrier:	b_0 = 0.920; b_1 = 0.993	b_0 = 0.974b; b_1 = 0.996b

Values followed by the same lowercase characters indicate identical statistical values.

Tables of statistical significance for each coefficient in all three models are available from the author.

To show combined effects of growth and mortality on plantings, we prepared illustrations of surviving volume over time. The equation used a cone of seedling height minus 2.54 cm (1 in) averaged over the treatment.

(6)

$$Vol/hec = \pi\left(\frac{Dia}{100}\right)^2\left(\frac{h}{2}\right)(Sur)(Stock) = \pi\left(\frac{Dia}{20000}^2\right)h(Sur)(Stock)$$

where:

Vol is average volume of surviving seedlings for the treatment

Dia is average seedling diameter at 2.54 cm (1 in) above groundline

h is average height for the treatment,

Sur is survival, and

Stock is the initial stocking rate in seedlings per hectare.

Equation 6 is derived from a physical model and contains no coefficients needing estimation.

Results

When we applied Barrett's (1978) site index model with both sites, every block, treatment, and interaction term, three among-sites differences, and most treatments were significant at $\alpha = 0.05$. Analysis of variance produced $F_{(10,3162)} = 1897.29$, FIT = 0.857 and standard error of 0.62 m (2.03 ft) (equation 2). Treatment coefficients are proportional to height, diameter, and survival. We used height to predict stem diameter at 0.0254 m (1 in) equation 4). R^2 was 0.893 with a standard deviation of 1.854 cm (4.71 in). Except for Scalp/Polymer, treatment coefficients were similar. To model survival probability we fit proportions of surviving seedlings determined from stem counts made each October, to equation 5 (tables 1 and 2). All FIT values were significant and similar (lowest FIT = 0.990).

Mule deer damage occurred at the Flagstaff site during the first and third winters. Seedlings at both sites were damaged by southwestern pine tip moth each year measurements were taken. Deer damage affected both growth and survival, while tip moths affected only height growth. When treatments were added to the model, deer and tip moth damage became insignificant ($\alpha = 0.950$).

By 1997, 6 and 7 years after seedlings had been planted at the Baseline and Flagstaff sites, respectively, the black plastic was reduced to fragments. Broad-leaved plants were re-invading space formerly covered by plastic. Nevertheless, seedlings in treatments that included plastic mulch were growing well (figures 2 and 3). By 2009, black plastic on both sites was completely gone and the weed barrier was so brittle it could not be moved without tearing. Weeds were coming up through the weed barrier, but by this time, seedlings were mostly suppressing weeds on their own. Weed barrier produced the highest surviving volumes of any treatment at both sites (figures 2 and 3).

We observed significant differences in grass suppression among treatments. Weed barrier treatment had the greatest suppression compared with control and polymer treatments (figures 2 and 3; table 1). Polymer treatment did not increase seedling performance

Table 1. Measured ponderosa pine seedling height and diameter at the Flagstaff site over time. At ages 2 to 6 means are not statistically different at $\alpha = 0.05$. At age 7 and older, means followed by the same letter are not statistically different from each other.

Age	Height (m)			Diameter (cm)			Survival (%)		
	Control	Plastic	Barrier	Control	Plastic	Barrier	Control	Plastic	Barrier
2	0.22	0.21	0.25	0.75	0.71	0.88	100	100	100
3	0.27	0.26	0.28	0.85	0.82	0.93	84	100	93
4	0.27	0.29	0.34	0.87	0.88	1.00	82	82	73
5	0.31	0.37	0.46	1.10	1.14	1.25	71	77	73
6	0.40	0.47	0.60	1.40	1.65	1.87	63	77	70
7	0.50a	0.61a	0.74b	1.86a	2.21a	2.48b	61a	73a	70a
20	2.92a	2.90a	3.38b	11.94a	12.16a	13.45b	39a	65b	47b
26	4.34a	4.11a	4.80b	13.40a	16.67a	14.75b	39a	65b	47b

relative to the control but appeared to have a negative effect, with some polymer treatments having lower morphological values and survival over time compared with the control (table 2, figure 3).

Discussion

Our findings are consistent with previous research (Maguire et al. 2009, Rose et al. 1999, Rose et al. 2008) in that the area around a seedling influencing its growth and survival is much larger than previously thought, and that early treatments have lasting effects. Maguire et al. (2009) used chemical site treatments on 5.57 m^2 (60 ft^2) plots with varying application frequencies over 5 years, and found that plots that were treated all 5 years had significantly greater height growth. Rose et al. (2008) showed that vegetation control around individual trees had a profound effect on stem volume of Douglas-fir seedlings (*Pseudotsuga menziesii* Mirb. Franco) 12 years after planting.

Our comprehensive literature search did not return any field studies that evaluated long-term effects of polymers, landscape fabric (weed barrier), large (greater than 91.4 cm [3 ft] on an edge) sheets of plastic, or combinations of these. In addition, we found few long-term studies of planting treatments dealing with ponderosa pine in Colorado, or of tree planting in the Colorado piedmont area, with the exception of Shepperd et al. (2006) who reported average ponderosa pine heights of 1.4 m (4.5 ft) 23 years after planting on a scarified site.

Table 2. Height, DBH, basal diameter, and survival of ponderosa pine seedlings at two sites in the Northern Front Range (Colorado).

Treatment	Height (m)	Basal diameter (cm)	DBH (cm)	Survival (%)
Flagstaff (age 28)				
Control	4.3	13.5	8.1	29
Plastic	4.1	16.8	9.1	59
Barrier	4.8	14.7	8.9	27
Baseline (age 27)				
Control	2.6	12.2	6.9	25
Scalp	4.7	23.6	13.2	30
Plastic	4.4	24.6	13.7	55
Polymer	2.2	12.4	7.1	10
SPla	4.7	25.4	14.2	65
SPoly	2.4	12.3	11.7	30
PPoly	4.5	24.4	13.7	80
SPP	4.8	25.4	14.2	65
PolyX2	3.4	18.3	10.2	15
Barrier	5.5	27.2	15.2	75

Treatment abbreviations are: SPla=Scalp&Plastic, SPoly=Scalp&Polymer, PPoly=Plastic&Polymer, SPP=Scalp, Polymer&Plastic, PolyX2=Double Polymer and weed barrier. DBH is diameter at breast height (54 in or 1.37 m). Basal diameter is at 2.54 cm (1 in) above groundline.

Unlike studies that have examined seedling field performance from a reforestation point of view (Rietveld and Heidman 1974, Rose et al. 1999, 2008; Shepperd et al. 2006), our study was based on treatments to improve windbreaks and shelter plantings. Under these

Figure 2. Regression models of height, basal diameter, survival, and volume over time at the Flagstaff (mountain) planting site. Models assume an initial stocking of 1500 seedlings/ha.

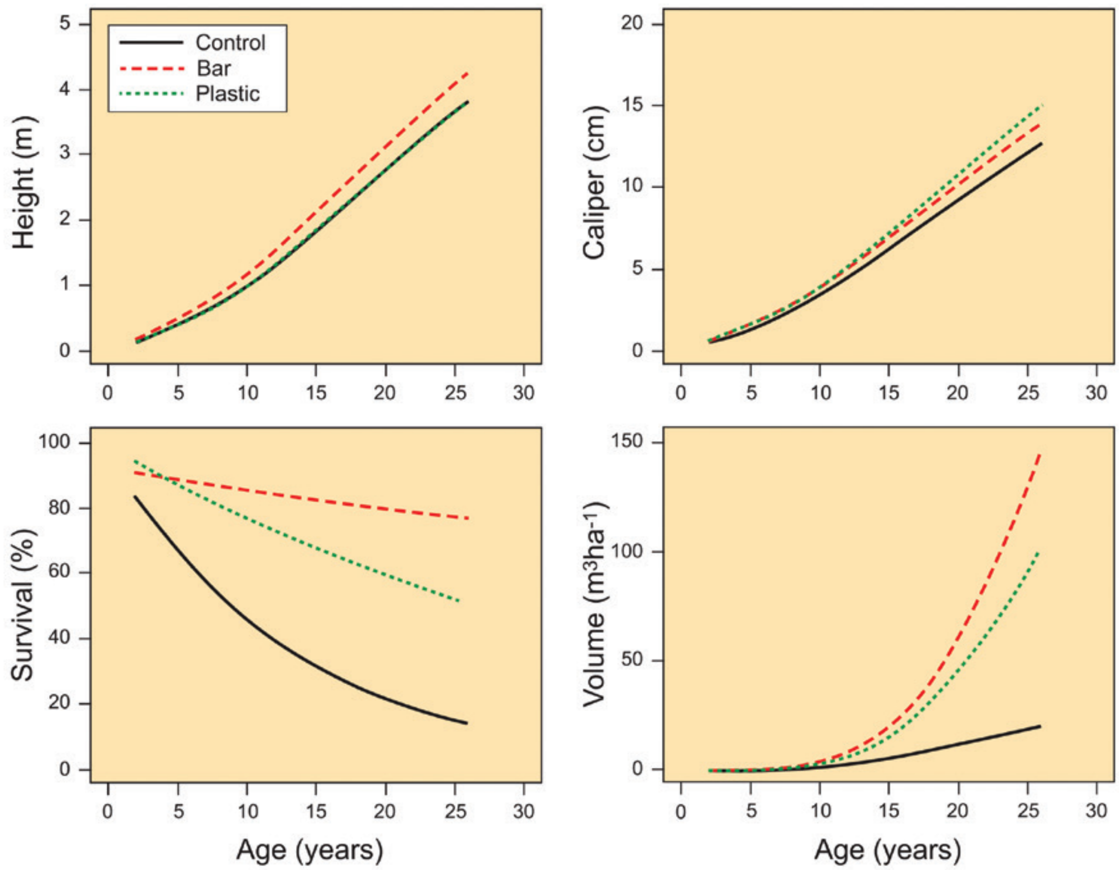
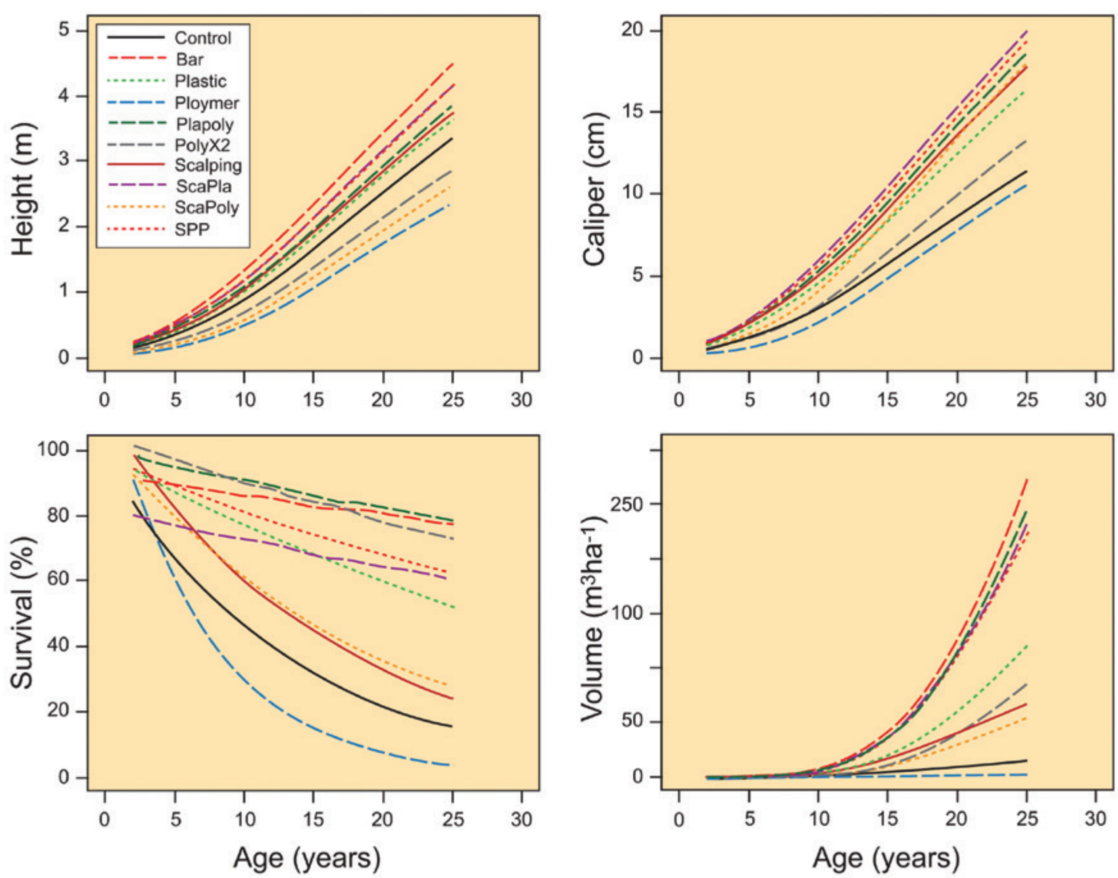


Figure 3. Regression models of height, basal diameter, survival, and volume over time at the Baseline (piedmont) planting site. Trees treated wtih Weed barrier (Bar), Plastic/ Polymer (PlaPoly) and Saclp/ Plastic/ Polymer (SPP) treatments did well in each metric. Models assume an initial stocking of 1500 seedlings/ha.



circumstances, high-cost treatments with high success rates might be a better investment than low-cost treatments with low success rates. Walker and McLaughlin (1989) used plastic mulch sheets around loblolly pine (*Pinus taeda* L.) and yellow-poplar (*Liriodendron tulipifera* L.) and found improved growth and survival compared with controls. Similarly, Lowenstein and Pitkin (1970) successfully prevented weed encroachment using black plastic mulch around pine seedlings and found significant increases in height growth after 5 growing seasons. Rietveld and Heidman (1974) reported no significant difference in survival between black polyethylene mulched trees and controls; while height growth was slightly improved using black polyethylene; they speculated that a "larger mulched area" would produce improved survival and growth. Rose et al. (1999) found that maximum growth response occurred between 5 and 6 m^2 (54 to 64 ft^2) of chemical control.

We noted on both sites that early season grasses (C_3), like smooth brome, were much more competitive than late-season (C_4) grasses. We suspect that grass allelotropes may be involved (Bonner 1950, Chung and Miller 1995, Myers and Anderson 1942). We found that treatments that reduce grass cover improve seedling growth and survival and are essential to planting success in the Northern Front Range and piedmont.

Polymer did not improve long-term seedling performance in our study. Al-Humaid and Moftah (2006), working with buttonwood (*Canocarpus erectus* L.), found that a polymer (Stocksorb) concentration of 0.4 to 0.6 percent resulted in twice as much soil water retention compared with unamended control soil. Callaghan et al. (1989) found that a 0.5 percent mixture of polymer to soil combined with watering at 3-day intervals increased survival of coolibah (*Eucalyptus microtheca* Blakely) from 0 to 100 percent over a 56-day trial. Orzolek (1993) reported 2.8 percent weight loss of polyacrylamide after 6 weeks in the ground and a 30 percent increase in tomato production. The Al-Humaid and Moftah (2006), Callaghan et al. (1989), and Orzolek (1993) studies, however, all used supplemental irrigation, suggesting that polymers must be re-wetted more frequently than the two or three precipitation events provided each season by naturally occurring summer storms. Although these researchers found notable short-term effects on growth and survival, our long-term study indicated that polymers may have no effect or a negative effect. Efficacy of hydrogel products can vary and have been known to increase mortality when seedlings are subjected to moisture stress following outplanting (Starkey et al. 2012). The ability to hold water in the soil has been well documented, but research results are mixed regarding hydrogel influences on water availability and plant uptake, and can vary by product and environmental conditions (Landis and Haase 2012).

Conclusions

Research on treatments at the time of planting is usually monitored for only a few years. Results after 1 to 3 years, however, may be more reflective of seedling treatment in the nursery and early seedling establishment than site treatments. Longer term studies (i.e., 10 or more years) can provide a more comprehensive evaluation of treatment effects (figure 4).

Mulch treatments need to be large enough to keep grass and weeds from reaching water that would otherwise be accessible to the seedling. Spot treatments should extend outward from the seedling for at least 0.91 m (3 ft), preferably more. Treatments that suppress grass, like scalping, plastic mulching, and particularly weed barrier, are the most effective at promoting seedling growth and survival. Although black plastic is not as effective as woven weed barrier, it is less expensive. Polymer treatments may not be effective unless supplemental watering is included. Further experimentation to determine the best polymer products and rates (if any) is needed.

Grass allelotropes may affect seedling growth and survival. This observation warrants further research. Our study shows that mulching treatments can result in successful ponderosa pine plantings on Ferncliffe and Nunn soils in the northern Front Range and piedmont. Similar studies are needed on other soil types.

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Figure 4. (a) Baseline site 30 years since planting. (b) The author at the Baseline site; the tree in the foreground was treated with weed barrier. (Photos by Cynthia Stevenson, 2019)

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