Soil Moisture, Soil Temperature, and Seedling Growth in Response to Interspecific Competition and Woody Debris in Northern Idaho

Joshua Mullane and Andrew S. Nelson

Graduate Assistant, Center for Forest Nursery and Seedling Research, College of Natural Resources, University of Idaho, Moscow, ID; Director of Franklin H. Pitkin Forest Nursery, Tom A. Alberg and Judith Beck Endowed Chair of Native Plant Regeneration, Associate Professor, College of Natural Resources, University of Idaho, Moscow, ID

Abstract

A study evaluated the effects of varying levels of competing vegetation and coarse woody debris on microsite conditions around Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *glauca* [Beissn.] Franco) and western larch (*Larix occidentalis* Nutt.) seedlings at a high-productivity site and a low-productivity site in northern Idaho. Five vegetation-control treatments (0-, 25-, 50-, 75-, and 100-percent control) were maintained for 2 years. Soil moisture was positively influenced by the presence of coarse woody debris and negatively influenced by increasing levels of competition. Seedling stem diameter tended to be larger when there was less competing vegetation. The findings of this study bring together the common practices of vegetation management and slash retention, showing how both can create a more hospitable planting site by lowering soil temperatures and maintaining higher levels of soil moisture in the summer. This paper was presented at The Reforestation Pipeline in the Western United States–Joint Annual Meeting of the Western Forest and Conservation Nursery Association, the Intertribal Nursery Council, and the Intermountain Container Seedling Growers Association (Missoula, MT, September 27–29, 2022).

Introduction

Microsite factors at the individual seedling level influence seedling growth and survival after planting (Harrington et al. 2013). The microsite comprises the immediate area around a seedling, in which competing vegetation, woody debris, microtopographical variation, and other biotic or abiotic factors exert immediate influence on seedlings. These small landscape variations are considered either a benefit or detriment to tree regeneration. For example, in regions where soil moisture is a major limiting factor for seedlings, coarse woody debris left after harvest can cast shade on seedlings, thereby reducing heat load and soil evaporation, which, in turn, increases seedling growth and survival (Harrington et al. 2013, Sass et al. 2018). The presence and intensity of vegetation in the microsite can compete with the seedling for resources but could also modify the microsite environment around the seedling and ameliorate extreme conditions (Balandier et al. 2006).

Soil moisture is the main limiting resource in young plantations in the Northwestern United States. The region experiences an annual growing season drought from midsummer through early fall each year (Abatzoglou et al. 2014) that coincides with active seedling growth. Within the first few years after planting, seedlings are particularly sensitive to these seasonal fluctuations in available soil moisture since most of their roots are in the upper soil profile (Pinto et al. 2016). Because seedlings need water for transpiration and photosynthesis, dry conditions can result in smaller seedlings (Harrington et al. 2013). Lower soil moisture levels can also coincide with reduced nutrient availability (Nambiar and Sands 1993, Powers and Ferrell 1996). In addition to environmental factors such as air temperature and vapor pressure deficit, vegetative cover can drive these localized reductions in soil moisture due to transpiration.

Seedlings themselves can also contribute to moisture loss and their own demise. Seedling growth increases can result in subsequent tradeoffs in overall survival (Chen and Nelson 2020, Philipson et al. 2014, Simard et al. 2006). With increased growth comes an increase in resource demand, which can either result in realized growth gains or increases in mortality, depending on how and when site resources are limited.

As soil absorbs energy due to latent heat or direct solar radiation, moisture is lost to evaporation from the soil surface. The rate at which evaporative losses occur is typically slower compared with vegetative transpiration losses, as moisture levels are often higher on sites where vegetation has been controlled (Powers and Ferrell 1996). As the soil surface dries, the albedo of the surface increases, which reduces the impacts of direct solar radiation. A "drying front" forms, which disrupts the hydraulic connectivity between the soil surface and the moisture below, thereby slowing subsequent evaporative losses (Dingman 2015).

In addition to reducing soil moisture, high temperatures can pose a threat to seedlings. A study in northern Idaho on ponderosa pine *(Pinus ponderosa* Lawson & C. Lawson) seedlings showed that soil-surface temperatures above 131 °F (55 °C) resulted in irreversible damage to seedling tissues at the soil level (Kolb and Robberecht 1996). The same study found that the temperature of soil water used by seedlings was significantly colder than soil surface temperatures at midday. This finding suggests that higher amounts of subsurface soil moisture can ameliorate lethal effects of midday surface temperatures on seedlings. Increased access to soil moisture allows seedlings to transpire at a greater rate, leading to increased water content in stem tissues and thus acting as a buffer against tissue-damaging temperatures.

The effect of competing vegetation on microsite soil moisture and temperature and its impact on seedling growth is not well understood in the Inland Northwest. To address this gap in knowledge, this study examined the effects of incremental reductions in competition intensity on growing season soil moisture, soil temperature, and growth of western larch (*Larix occidentalis* Nutt.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *glauca* [Beissn.] Franco) seedlings at two sites that differed in productivity in northern Idaho.

Methods

Site Descriptions

The study included two sites in northern Idaho with differing site productivities (low and high) (figure 1). Site productivity classification was based on a modeled Douglas-fir site index for northern Idaho (Kimsey et al. 2008). The model includes a range of factors to estimate Douglas-fir productivity, including edaphic factors, such as parent material and ash mantle thickness; terrain factors, such as elevation, slope, and aspect; and environmental factors, such as mean annual precipitation. Site index (base age 50) was 104 ft (31.7 m) at the high-productivity site and 70 ft (21.3 m) at the low-productivity site.

The high-productivity site is located approximately 42 mi (67.6 km) east of Moscow, ID (46.671294 °N, -116.112895 °W). The site is situated at an elevation of 3,307 ft (1,008 m) above sea level, with an average slope of 16 degrees. The soils at this site are characterized by basalt parent material overlaid by a volcanic ash mantle. Average annual precipitation is 44 in (112 cm). The site has a northeast aspect.

The low-productivity site is located approximately 25 mi (40.2 km) east of Moscow, ID (46.700427 °N, -116.461105 °W). The elevation of this site is 3,376 ft (1,029 m) above sea level, with an average slope of 25 degrees. Soil parent material consists of gneiss and schist, with a mix of surficial volcanic ash and loess. Average annual precipitation is 37 in (94 cm). The site has a northwest aspect.

Both study sites are within operationally managed conifer stands. As such, each site was previously harvested, chemically site prepped, and then planted on a 10- by 10-ft spacing. The high-productivity site was chemically site prepped in July 2017 with a combination of glyphosate and imazapyr, and the low-productivity site was chemically site prepped in April 2018 with a mixture of glyphosate and atrazine. Both sites were planted in spring 2018. All seedlings were grown in 415C Styroblock® containers (91 cavities per block, 7.9-in^3 [130-ml] rooting volume; Beaver Plastics, Acheson, AB) at a private nursery in the Pacific Northwest. The seed lots for both species were sourced from genetically improved seed orchards and matched the elevation and seed zone of the sites.

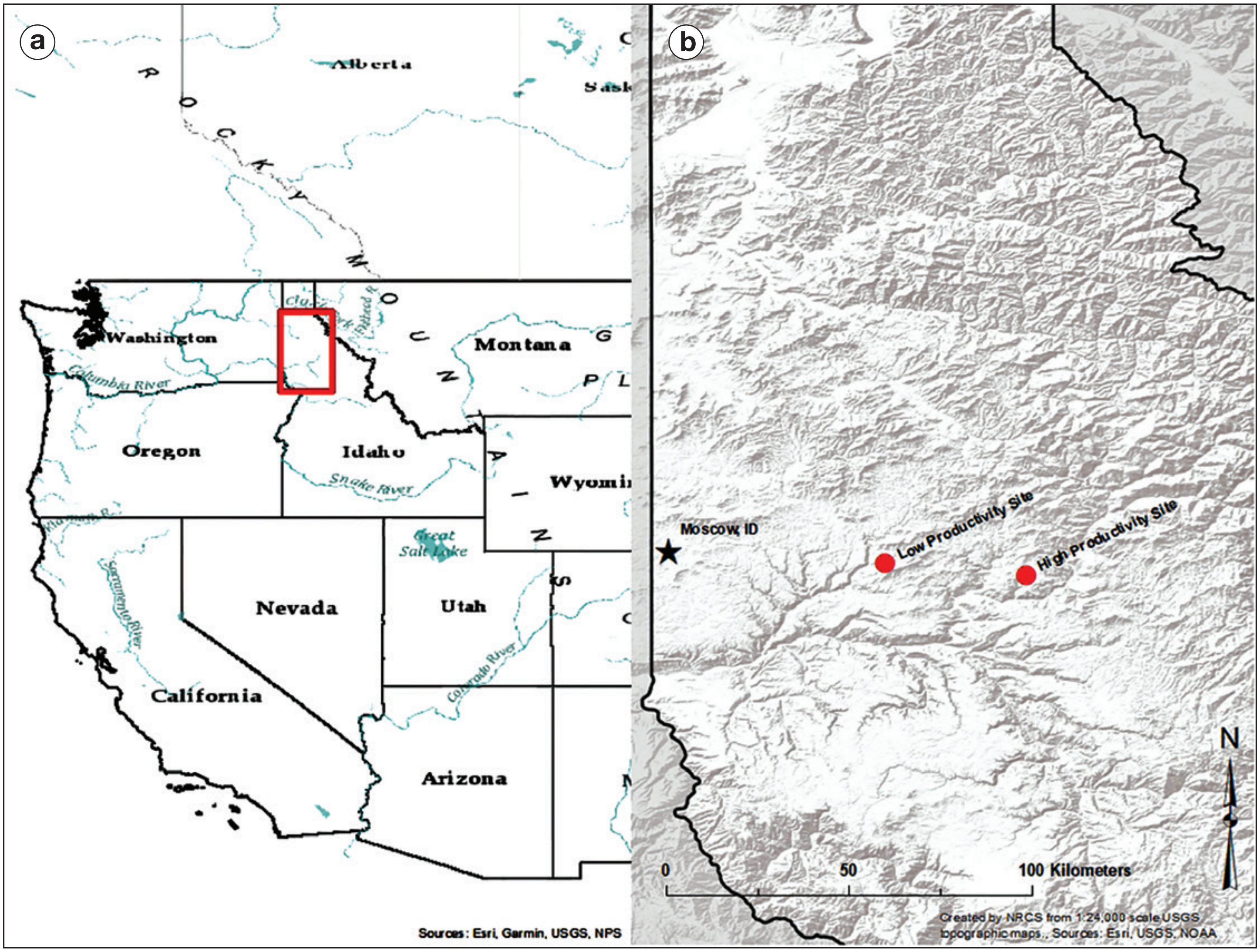

Figure 1. The study was conducted in northern Idaho. These maps show an outline of northern Idaho within the context of (a) the Western United States and (b) the detailed location of the two study sites.

Treatments

Thirty seedlings of each species (Douglas-fir and western larch) were randomly selected, tagged, and numbered at each site in May 2019. A 16-ft^2 (1.51 m^2) plot was delineated around each seedling and defined as the seedling microsite. Each plot was oriented with respect to the slope and then divided into four equal quadrats with the seedling located in the middle (figure 2).

The study contained five treatments, each randomly assigned to six seedlings per species. Treatments were 0-, 25-, 50-, 75-, and 100-percent vegetation control (figures 3 and 4) achieved via directed application of 7-percent glyphosate solution with 1-percent nonionic surfactant applied with a hand sprayer. Seedlings were protected from drift by a clear plastic bag placed over the seedling during application and removed after the herbicide dried (figure 5). After the initial herbicide application, treatments were maintained monthly as needed throughout the 2019 and 2020 growing seasons (May to September) using the same chemical prescription. When low densities of new weed germinants emerged between chemical applications, they were removed by hand instead of spraying with herbicide.

Measurements

Competing vegetation within each quadrat (percent cover by each plant species to the nearest 5 percent) before applying treatments (May 2019) and again in July 2019 and July 2020. Cover by species was summed in each quadrat and the mean total cover was calculated across the four quadrats. Due to this additive approach, total estimated cover within a

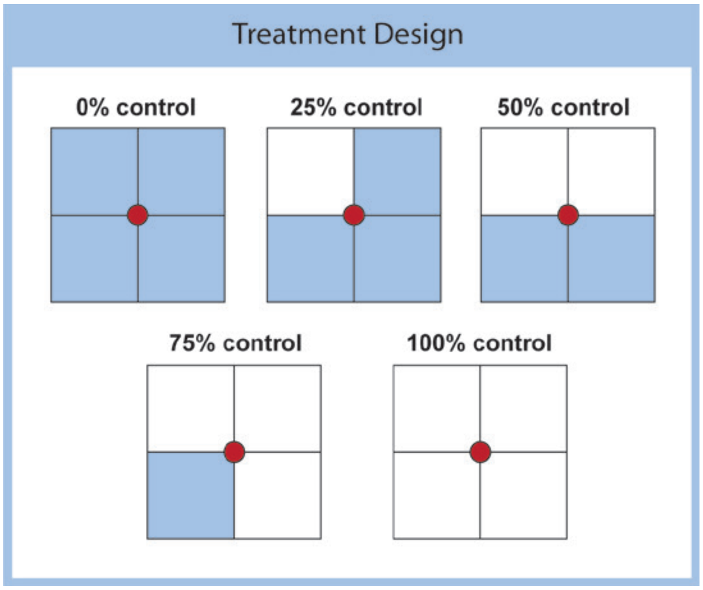

Figure 2. Treatments were designed to control competing vegetation in different quadrats around each seedling. The white squares represent quadrats that were frequently treated with glyphosate to maintain vegetation-free conditions, and blue squares represent untreated quadrats. The circle in the middle represents the planted seedling. Treatments were randomly assigned to each seedling.

Figure 4. In the 100-percent control treatment, all competing vegetation was controlled around the seedling in a 16-ft^2 square with the seedling in the center. This picture shows a 100-percent control treatment for a Douglas-fir seedling affixed with pink flagging at the high-productivity site 1 month after applying herbicide. The competing vegetation surrounding the control area reflects the intensity of competition around the seedling prior to treatment. (Photo by Andrew Nelson)

quadrat could exceed 100 percent for a given life form, as the foliage of multiple species could be layered vertically within the same area. In addition to competing vegetation, coarse woody debris cover (>0.4 in [10 mm] in diameter) was measured once during the study (July 2019).

Microsite environmental conditions were quantified by measuring soil moisture and temperature. A portable time-domain reflectometry soil moisture probe (HydroSense II, Campbell Scientific, Logan, UT) was used to measure soil moisture from May through October each year. The 7.9-in (20-cm) probes were inserted vertically into the mineral soil within each of the four quadrats around each seedling and within 6 in (15.2 cm) from the base of the seedling. Temperature sensors (iButton Thermochron, models DS1921G-F5 and DS1922L-F5, Maxim Integrated, San Jose, CA) were placed 0.8

Figure 3. All competing vegetation was completely controlled within a quadrat around a seedling based on the treatment. This picture shows an example of a 25-percent vegetation-control treatment around a western larch seedling at the high-productivity site. The seedling is located in the middle near the orange flag. The blue paint dots on the ground divide the microsite around the seedling into four quadrats. (Photo by Andrew Nelson)

Figure 5. Seedlings were covered with a plastic bag when glyphosate herbicide was applied to control surrounding competing vegetation, minimizing the chance of damage from herbicide contact. The bags were removed from the seedlings once the herbicide dried to avoid overheating. (Photo by Andrew Nelson)

in (2 cm) downhill from each seedling at a depth of 0.8 in (2 cm) into mineral soil in May of each year and set to record temperature at 1-hr intervals until October when they were removed (figure 6).

Root-collar diameter (RCD) of every seedling was measured at ground level in May 2019 when the study began and at the end of each growing season (October) for both years. Height was measured monthly from May (prior to initial treatment) through October of both growing seasons. During the May 2019 measurement, the height of the previous year's bud scar was measured to estimate height at time of planting. Survival was also monitored, although none of the seedlings died during the experiment.

Experimental Design and Data Analyses

The study installation was a completely randomized design with six replicate seedlings per species per treatment at each site. Each species at each site was analyzed independently for soil moisture, soil temperature, RCD, and seedling height using the R version 4.0.4 (R Core Team 2021). The total vegetation cover in July of each year was used as the competition covariate in all analyses. Main effects tested included year, total vegetation, and coarse woody debris. For soil moisture and temperature, month was also tested in the models. Soil moisture and temperature data were filtered to only include June, July, and August of each year to reduce noise and focus on the portion of the growing season in which moisture is most frequently limiting. For seedling RCD and height at the end of the growing season, initial RCD and height at the beginning of the study (May 2019) were included as covariates. The RCD and height models also tested soil moisture and August maximum soil temperature for significance, but both variables were consistently not correlated with RCD or height and thus dropped from the final models. Significance was determined at $\alpha = 0.10$.

Figure 6. iButton sensors (silver button near the seedling base) were buried immediately below the soil surface near each seedling to measure soil temperature throughout the two growing seasons. (Photo by Andrew Nelson)

Results

Soil Moisture and Temperature

Soil moisture decreased from May to August each year for both species at both sites (figure 7). Soil moisture was negatively correlated with vegetation cover except for the Douglas-fir plots at the high-productivity site (figure 8, table 1). Competing vegetation was negatively correlated with soil temperature only for the Douglas-fir plots at the high-productivity site ($p < 0.001$, table 2). Comparatively, coarse woody debris was negatively correlated with soil temperature in the western larch plots at both sites ($p < 0.001$). Soil temperature increased from May through August, with the greatest soil temperature of 87.5 °F (30.8 °C) at the high-productivity site in August 2020 and 92.5 °F (33.6 °C) at the low-productivity site in July 2019 (figure 9).

Seedling Morphology

Seedling RCD was negatively correlated with competing vegetation for Douglas-fir at the high-productivity site and western larch at both sites (table 3, figure 10). Comparatively, coarse woody debris was only correlated with western larch RCD at the low-productivity site ($p = 0.012$) but not any of the other species and site combinations. The only significant factor for total height besides year and initial height was competing vegetation for western larch at the high-productivity site ($p = 0.017$).

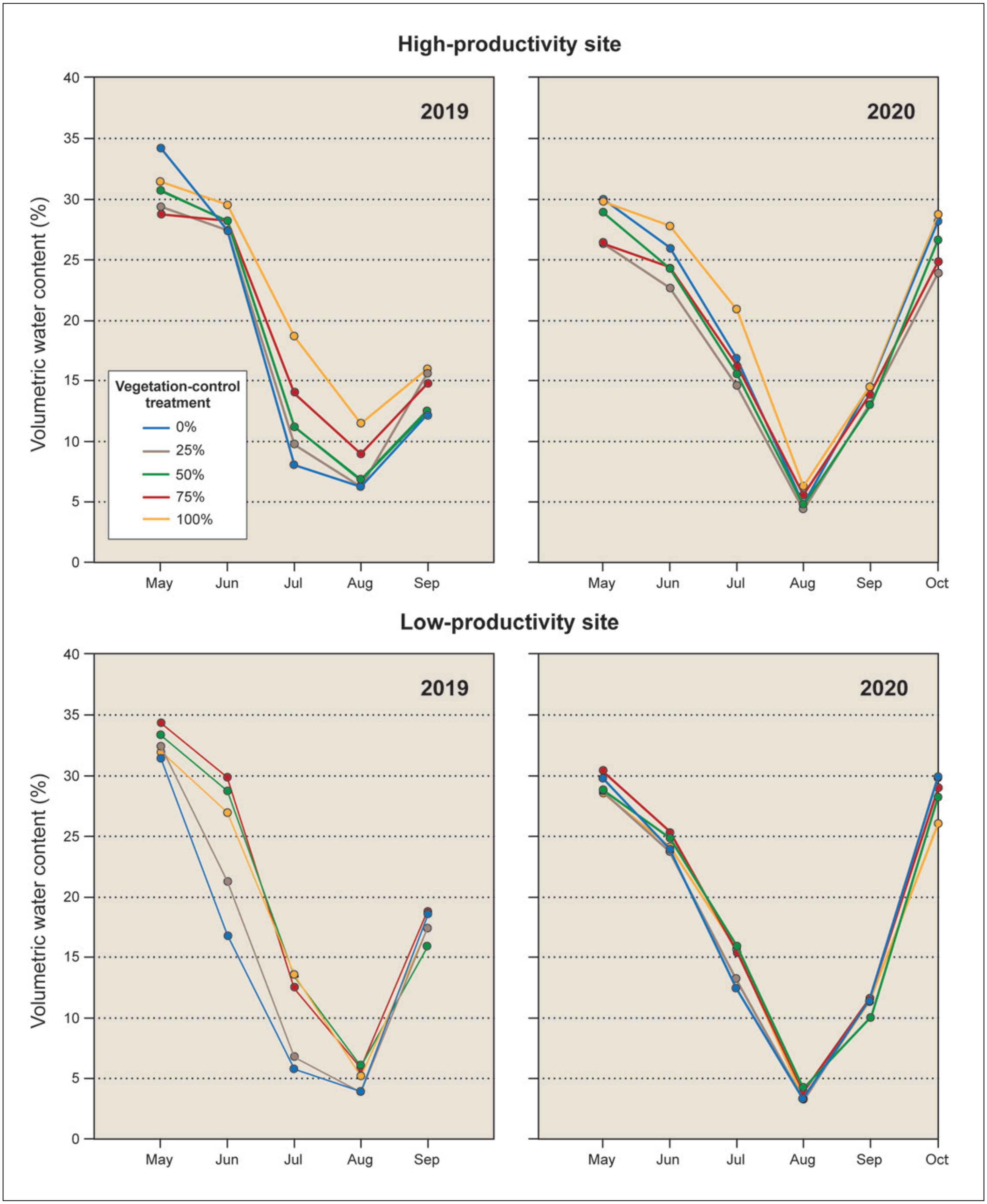

Figure 7. Volumetric soil water content decreased between May and August each growing season, reaching their lowest values in August after approximately 8 weeks of no precipitation. Soil moisture was relatively higher in the 100-percent control treatment at the high-productivity site during the summer drying period. Soil moisture then increased in September and October as fall precipitation occurred.

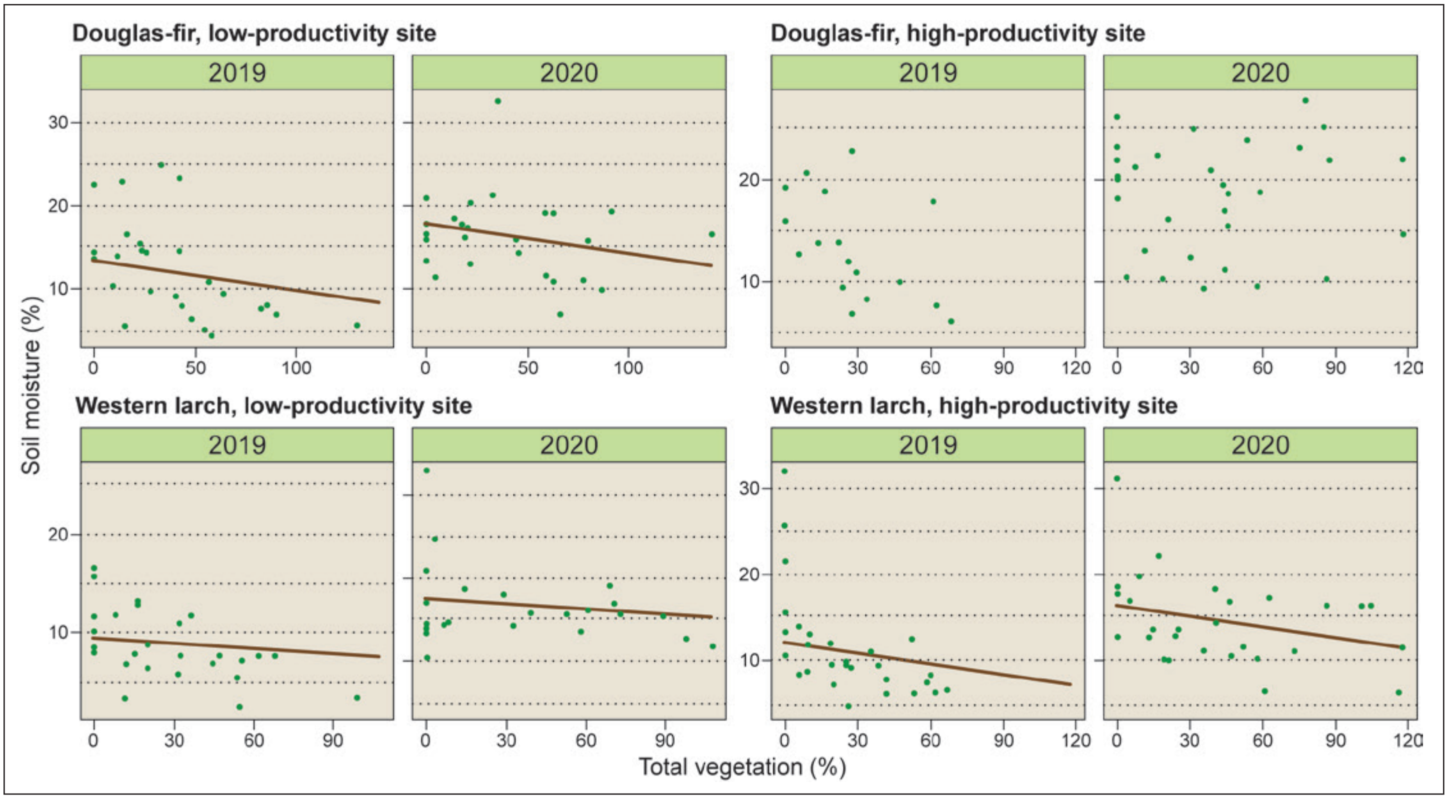

Figure 8. Soil-moisture in August was generally lower with increasing cover of competing vegetation around seedlings of Douglas-fir and western larch at the high- and low-productivity sites during the 2019 and 2020 summer growing seasons. The one exception was Douglas-fir at the high-productivity site, where competing vegetation and soil moisture were unrelated.

Table 1. P-values from the soil-moisture models for each species and site productivity combination. Significance was assessed at the $\alpha = 0.10$ level.

	Douglas-fir		Western larch	
	High productivity	**Low productivity**	**High productivity**	**Low productivity**
Year	0.317	0.118	0.425	0.836
Month	<0.001	<0.001	<0.001	<0.001
Total vegetation	0.931	<0.001	0.001	0.006
Coarse woody debris	0.013	0.761	0.856	0.001
Year x month	<0.001	0.008	<0.001	<0.001
Model adjusted r^2	0.7920	0.7902	0.7442	0.8349

Table 2. P-values and model r^2 values for soil temperature models. Significance was assessed at the $\alpha = 0.10$ level.

	Douglas-fir		Western larch	
	High productivity	**Low productivity**	**High productivity**	**Low productivity**
Year	0.005	<0.001	0.0155	<0.001
Month	<0.001	<0.001	<0.001	<0.001
Total vegetation	<0.001	0.665	0.835	0.617
Coarse woody debris	0.818	0.978	<0.001	<0.001
Year x month	0.003	0.912	0.001	0.039
Model adjusted r^2	0.5592	0.4155	0.4789	0.7125

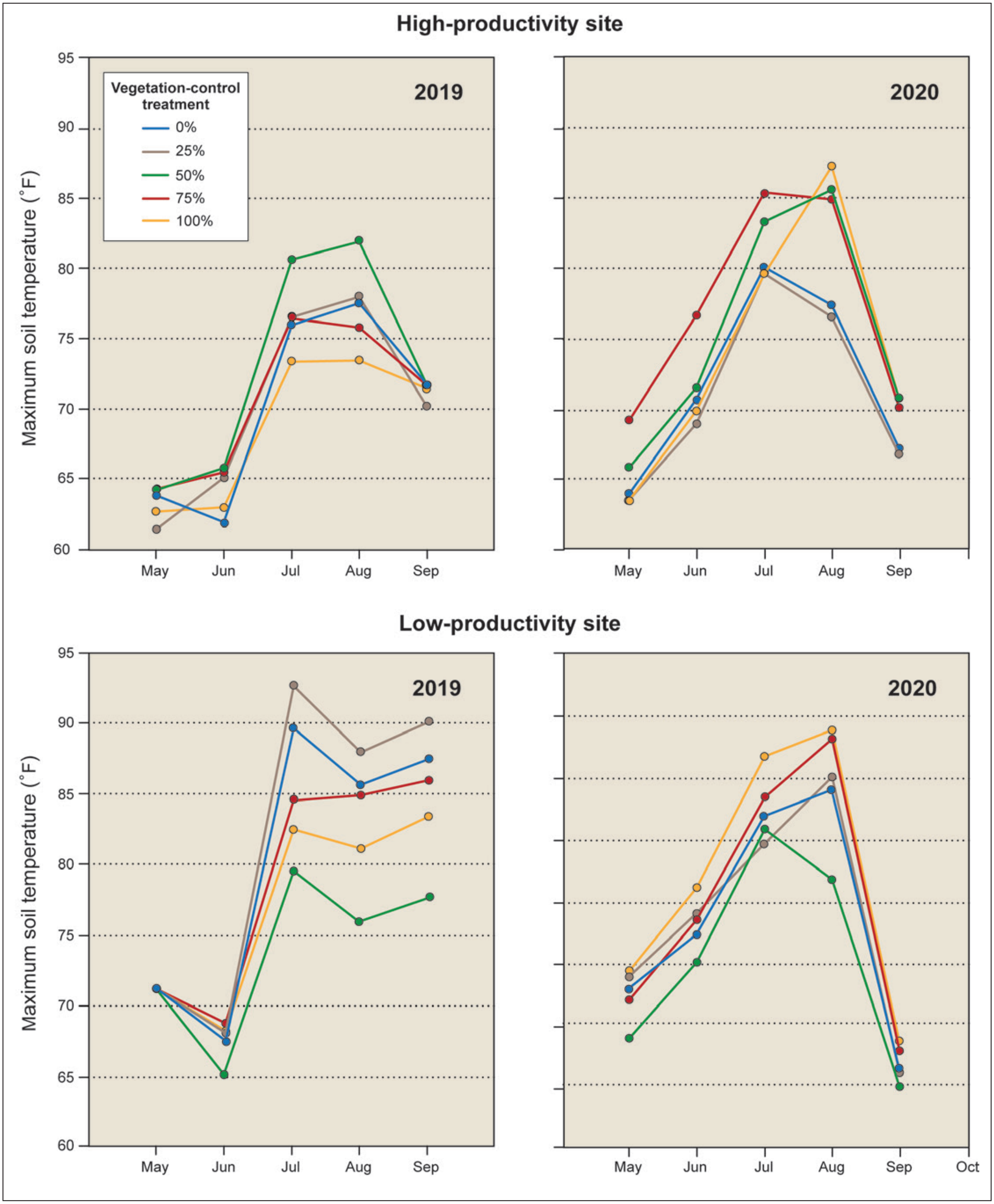

Figure 9. Maximum monthly soil temperature increased between May and August as air temperature increased and precipitation declined. Soil temperature peaked in August and then declined substantially except in 2019 at the low-productivity site where maximum soil temperature remained similar to soil temperature in August.

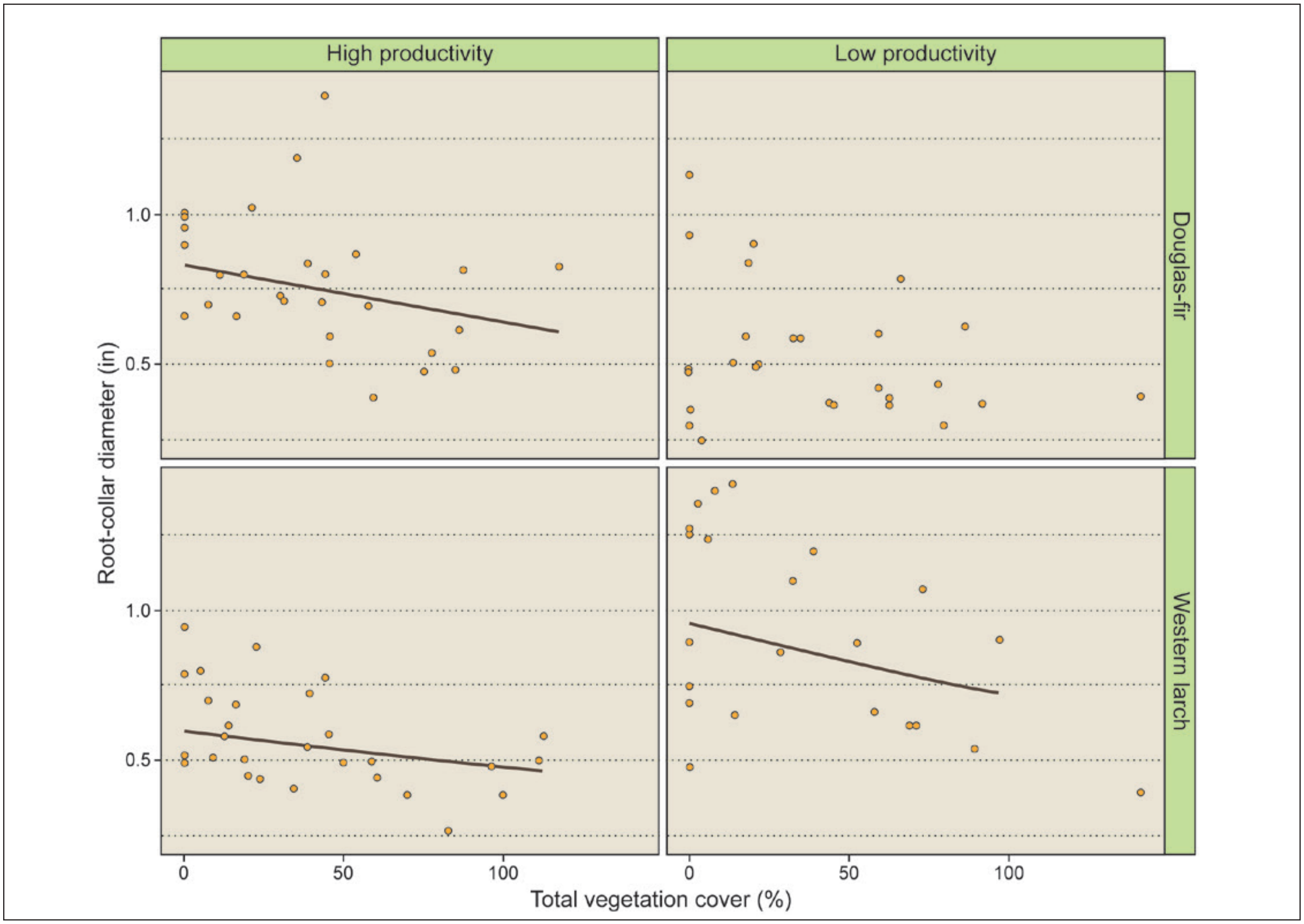

Figure 10. Seedling root-collar diameter (RCD) at the end of the second growing season (2020) was lower with increasing competing vegetation cover for Douglas-fir at the high-productivity site and western larch at both sites. A significant correlation between RCD and competing vegetation cover was not detected for Douglas-fir at the low-productivity site.

Table 3. P-values from analysis of second-year root-collar diameter and seedling height models for Douglas-fir and western larch seedlings assessed at the $\alpha = 0.10$ level.

	Douglas-fir		Western larch	
	High productivity	**Low productivity**	**High productivity**	**Low productivity**
		Root-collar diameter		
Intercept	<0.001	<0.001	<0.001	<0.001
Year	<0.001	<0.001	<0.001	<0.001
Initial diameter	<0.001	<0.001	<0.001	0.004
Coarse woody debris	0.883	0.104	0.008	0.756
Total vegetation	0.022	0.111	0.019	0.059
Model adjusted r^2	0.7534	0.6868	0.6870	0.6314
		Seedling height		
Intercept	<0.001	<0.001	<0.001	<0.001
Year	<0.001	<0.001	<0.001	0.011
Planting height	0.002	<0.001	0.018	0.047
Coarse woody debris	0.479	0.184	0.120	0.260
Total vegetation	0.173	0.606	0.017	0.322
Model adjusted r^2	0.5153	0.6899	0.4758	0.2604

Discussion

Soil moisture varied by growing season month, declining from May to August. This aligns with regional climatic patterns where precipitation is limited between early July and mid-September in northern Idaho (Abatzoglou et al. 2014). Total vegetation cover was correlated with soil moisture except around Douglas-fir seedlings at the high-productivity site. This negative correlation is well documented across the Pacific Northwest, including at a site with a similar climate in northeastern Oregon where soil moisture remained higher longer into the summer growing season when vegetation was controlled (Cole et al. 2018).

The positive correlation between soil moisture and coarse woody debris for Douglas-fir plots at the high-productivity site and western larch plots at the low-productivity site suggests that the debris may have reduced soil evaporation and limited suitable space for weeds to germinate and grow. Harrington et al. (2013) found similar results at two sites in western Washington and Oregon, where soil temperatures were negatively correlated and soil moisture was positively correlated with coarse woody debris; they attributed these results to less herbaceous cover. Similarly, Roberts et al. (2005) found that removal of coarse woody debris resulted in lower soil moisture, which likely occurred due to increased evaporation.

As summer progressed, soil temperature increased until reaching its annual maximum in July and August. Unlike soil moisture, total vegetation did not consistently influence soil temperature except on the high-productivity Douglas-fir site, where soil temperature was negatively correlated with competing vegetation. Increased amounts of vegetation may shade the soil surface, thus reducing surface temperature. Coarse woody debris was negatively correlated with soil temperature for western larch at both sites, which reinforces the possibility that shading from coarse woody debris may lower soil temperature. Devine and Harrington (2007) found that soil shading from mulch increased variation in soil temperatures, likely due to the scattering of material across the site.

The negative correlation between RCD and total vegetation at the high-productivity site was unexpected since resource competition tends to be greater on more xeric sites (Cole et al. 2018, Powers and Reynolds 1999). These studies and others have also found significant correlation between soil moisture and seedling size under different competition intensities, although soil moisture in the current study was not a significant factor. This difference from other studies could be attributed to the relatively mild moisture stress conditions during the 2019 and 2020 growing seasons. In addition, the volcanic ash mantle in the upper soil horizons has a high moisture-holding capacity (Kimsey et al. 2007).

Conclusion

Our results showing larger RCD with less competition supports prior research showing beneficial short- and long-term effects of vegetation control on tree growth (Cherico et al. 2020, Powers and Reynolds 1999, Wagner et al. 2006). Less often, these effects are paired with changes in soil moisture and temperature. Even though soil moisture was not a significant factor for seedling size, similar trends in correlations of lower soil moisture and RCD with greater competition suggests a link between moisture and size. Planting seedlings in favorable microsites may increase shade around a seedling, ameliorating some of the harsh effects of direct solar radiation during the summer on both the seedling and soil surrounding the seedling. The result is often increased survival and growth on harsh sites when proper microsite conditions are paired with competition control (Reely and Nelson 2021).

Address correspondence to—

Andrew S. Nelson, Tom A. Alberg and Judith Beck Endowed Chair of Native Plant Regeneration, Center for Forest Nursery and Seedling Research, College of Natural Resources, University of Idaho, 875 Perimeter Dr. MS 1133, University of Idaho, Moscow, ID 83843; email: asnelson@uidaho.edu; phone: 208–885–1004.

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