Wild high-elevation population of silvery lupine (*Lupinus argenteus* Pursh [Fabaceae]) on the Wasatch Plateau near the research plots (see Figure 1).

Comparisons of cultivation methods for *Lupinus sericeus*, *L. argenteus*, *L. prunophilus*, and *L. arbustus*

Covy D Jones, Jason M Stettler, Scott L Jensen, Bryan G Hopkins, Von D Jolley, Dave Turner, and Mikel R Stevens

ABSTRACT

Fire and invasive weeds have increased the demand for native seed for restoration across the Great Basin region of the US. Cultivation of native forbs could provide less-expensive seed in necessary quantities to meet restoration needs that cannot be harvested from wildland populations alone. We evaluated 2 cultivation methods of 4 lupine species (*Lupinus* (Tournefort) [Fabaceae])—hairy bigleaf lupine (*L. prunophilus* M.E. Jones), silky lupine (*L. sericeus* Pursh), silvery lupine (*L. argenteus* Pursh), and longspur lupine (*L. arbustus* Douglas ex Lindl.)—to evaluate emergence, establishment, and seed production. We compared the conventional cultivation method of row crop production (control) using direct drilling to an experimental cultivation method of broadcast seeding with a mulch covering of sawdust and N-Sulate fabric (covered treatment). Under covered treatment conditions, emergence was significantly improved compared to conventional cultivation for all 4 lupine species, with P values of < 0.0001 for all 4 species. Similar results were found in 2nd-year establishment rates for silvery lupine, hairy bigleaf lupine, and silky lupine with all P values < 0.0001. Longspur lupine showed symptoms of iron deficiency chlorosis during the 1st growing season and consequently no plants established in subsequent years. Silvery lupine and silky lupine produced significantly more seed in the covered treatment than in the control with P values of < 0.0001 for both species. Our mulch treatment effectively increased emergence, establishment, and seed production in all surviving cultivars compared to the control method.

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KEY WORDS

cultivation, native forbs, restoration, seed production, broadcast seeding, drill seeding, N-Sulate fabric, Fabaceae, Poaceae

NOMENCLATURE

USDA NRCS (2018)

Photos by Covy D Jones

The Great Basin is the largest desert in North America—covering more than 73 million ha (180.4 million ac) across the states of Utah and Nevada as well as portions of Idaho, Oregon, and California. In the late 1800s and early 1900s, early settlers of the Great Basin mined precious metals and ranched. An 1890 census recorded 3.8 million sheep and 0.5 million cattle in Utah, and most of these animals grazed in the Great Basin during at least some part of the year (Harrison and others 2003).

Many native plant communities experienced a "detrimental change in composition structure" due to heavy grazing (Vavra and others 2007). These impacted areas were then invaded with cheatgrass (*Bromus tectorum* L. [Poaceae]). This non-native weedy species is among the most deleterious invasives found in the Great Basin. Cheatgrass was noticed as early as 1916 in the West and is currently the most prolific plant in the Great Basin (Morrow and Stahlman 1984). This weedy annual grass invades weakened ecosystems and shortens fire frequency intervals from historic 30 to 100 y to as few as 3 to 5 y (Whisenant 1989; Peters and Bunting 1994). Additionally, it provides a reduced and poor nutrition supply of vegetative foodstuffs for animals in these fragile systems. The Great Basin lower elevation native ecosystems are not adapted to such abbreviated fire intervals, resulting in their quick disappearance from the landscape. In 2000, the Bureau of Land Management (BLM) estimated that at least 10 million ha (24.7 million ac) of the public lands of the Great Basin are dominated by cheatgrass (Borman 2000).

In 2000, the Great Basin Native Plant Selection and Increase Project began. This project, now identified as the Great Basin Native Plant Project (GBNPP), is a joint effort between the BLM, USDA Forest Service Research, and outside cooperators. The purpose of this collaboration is to increase the supply of native plant materials for restoration, to manage or restore seed resources on wildlands, to develop technology to improve the diversity of near monoculture crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) stands, and to provide technology transfer (Shaw and others 2005). To increase the supply of native forb seed, researchers focus primarily on developing plant materials, seed technology, cultural practices for seed production, and strategies for establishing selected species (Shaw and others 2008).

Active habitat restoration using native plant materials, both pre- and post-fire, is critical to preserving biodiversity in the Great Basin. Native shrub and grass seed are marketed in quantities and prices that allow for landscape-scale restoration projects. Native forb seeds, however, are largely unavailable or expensive (Shaw and others 2005) because of the difficulty in achieving stable and consistent seed production in native rangeland environments given the seasonal and annual variation of rainfall and temperature during flowering, seed development, and seed set (Shock and others 2016). An alternative to wildland-harvested seed is commercial agricultural seed production, which is currently being evaluated for many native species (Shaw and others 2005).

A major issue in cultivating native species for seed production is that many native forb species are not well adapted to row crop production because of diseases related to sprinkler irrigation (Shock and others 2016, 2017) and poor plant establishment. Subsurface drip irrigation may reduce weed and fungal disease pressure by reducing the soil surface and plant canopy wetting that occurs from sprinkler irrigation (Shock and others 2016). However, subsurface irrigation affects seedling growth only after roots have reached a sufficient level of development. Seed germination of many native species requires a stratification period (Baskin and Baskin 1998), whereas seedling survival is dependent on timely emergence and root development. Seedlings that emerge too soon are at high risk of winterkill or frost damage, whereas those that emerge too late are at risk of drying out. Developing roots must outgrow the depleting soil moisture profile while acquiring adequate water for the maturing plant. The rate at which the soil moisture dries is mostly dependent on winter precipitation, timing of spring precipitation, and spring temperatures. In wildland settings, soil cover (plant debris or mulched wood) has been shown to improve emergence and seedling growth rate in pinyon–juniper restoration communities (Young and others 2013).

N-Sulate fabric (DeWitt Company, Houston, Texas) is designed to protect gardens, flowering annuals, bedding plants, and vegetables from freezing temperatures by creating and prolonging a warm, moist microenvironment. N-Sulate fabric proved to be beneficial in a winter survival study of winter creeper (*Euonymus fortunei* (Turcz.) Hand.-Maz. [Celastraceae]) and Japanese holly (*Ilex crenata* Thunb. [Aquifoliaceae]) using 6-mo-old root stock (Regan and others 1990). Although this fabric has been used for seedling emergence and establishment of several native species (Grubb 2007; Fleege 2009; Shock and others 2016, 2017), no statistical evidence supports the benefits of N-Sulate fabric on germination, emergence, and establishment.

Lupines (*Lupinus* L. (Tournefort) [Fabaceae]) are legumes and are a critical component of the Great Basin shrub-steppe ecosystems. Lupines can enhance biodiversity, assist in soil stabilization and erosion control, supply wildlife and livestock forage, and provide important pollinator habitat (Matthews 1993; Shaw and others 2005; Beuthin 2012; St John and Tilley 2012). Four species of lupine are common throughout most of the Great Basin and are integral members of the sagebrush and pinyon–juniper plant communities with broad distributions throughout the western US (Welsh 2003). These species are longspur lupine (*L. arbustus* Douglas ex Lindl.), silvery lupine (*L. argenteus* Pursh), hairy bigleaf lupine (*L. prunophilus* M.E. Jones), and silky lupine (*L. sericeus* Pursh). We have conducted another study on various scarification methods to improve the

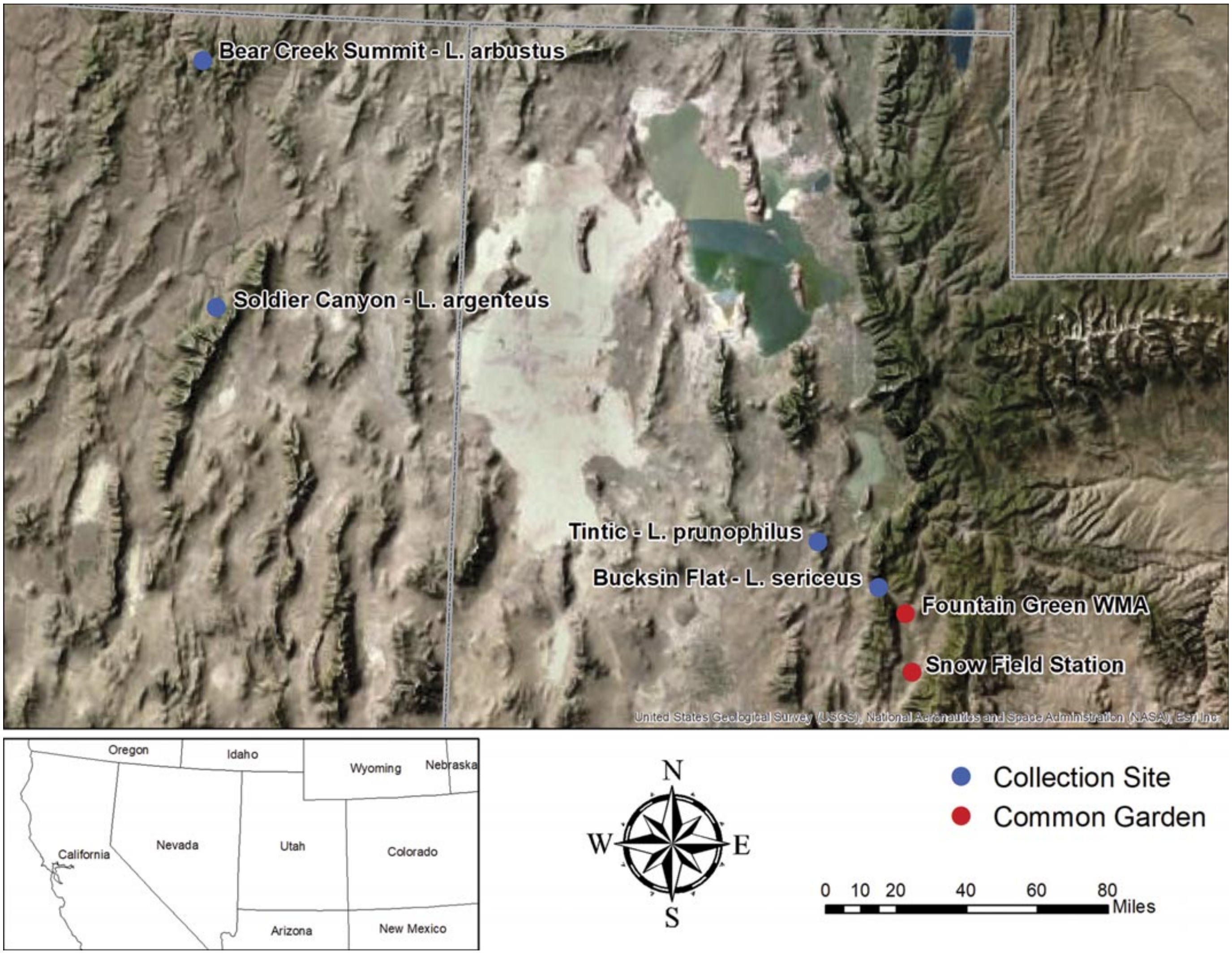

Figure 1. Map detailing lupine germplasm collection sites and common-garden locations in the eastern Great Basin.

germination of these 4 lupine species, which encourages further development of methods to more effectively establish seedlings in the conditions of the Great Basin (Jones and others 2016).

In an effort to develop improved cultural practices and to provide important agronomic information for seed production of the above listed Great Basin native lupines, we evaluated 2 planting methods for emergence, establishment, and seed production responses. Specifically, we compared the planting methods of conventionally drilling seed rows (control) to that of broadcasting the seed on the soil surface and then mulching these seed with sawdust and N-Sulate fabric (covered treatment). We hypothesized that the broadcast seed with the sawdust and N-Sulate fabric treatments would result in increased emergence and, consequently, have superior establishment and seed production for all 4 species included in this study compared to conventional row crop practices.

MATERIALS AND METHODS

Germplasm, Study Area, and Plot Design

In June and July 2007, we collected seed from our 4 target lupine species. Two sites were located in central Utah at the eastern edge of the Great Basin (hairy bigleaf lupine and silky lupine) and 2 sites in north-central Nevada (longspur lupine and silvery lupine) (Figure 1; Table 1).

We planted the common gardens at 2 sites: the Fountain Green Wildlife Management Area (WMA) farm near Fountain Green, Utah, and the Snow Field Station near Ephraim, Utah (Figure 1; Table 1). The Fountain Green WMA farm receives an annual average of 30 cm (12 in) of mostly wintertime annual precipitation and has a loam soil (Keigley silty clay loam and Mountainville cobbly fine sandy loam soil classes). The Snow Field Station is 30 km (18.6 mi) southeast of Fountain Green and receives an annual average of 27 cm (10.6 in) of mostly

TABLE 1

Germplasm collection sites and research locations.

Site name	Lupine species collected	Latitude	Longitude	Elevation (m)	General location
Bear Creek	Longspur lupine, *L. arbustus*	41.8377537	–115.4565113	2469	North-central NV
Soldier Canyon	Silvery lupine, *L. argenteus*	40.8012972	–115.3565112	1768	North-central NV
Tintic	Hairy bigleaf lupine, *L. prunophilus*	39.9632181	–112.0951638	1950	Central UT
Buckskin Flat	Silky lupine, *L. sericeus*	39.6843129	–111.6769766	1920	Central UT
Research location	**Common garden**				
Ephraim, UT	Snow Field Station	39.36996	–111.57832	1686	Central UT
Fountain Green, UT	Fountain Green WMA farm	39.61010	–111.61764	1749	Central UT

wintertime precipitation and has a clay loam soil (Genola loam and Woodrow silty clay loam soil classes). Each common garden was planted using a randomized complete block design with 5 replications in each location. We arranged each field trial in a split-plot experimental design. The experimental plots for each species within each block were 23 m long and 1.5 m wide (75 ft × 5 ft) (34.5 m² [375 ft²]), with a 2 m wide (46 m² [150 ft²]) buffer area between plots.

Plot Preparation, Seeding, Emergence, and Establishment

In October 2007, subsurface drip irrigation systems were installed using a single tooth ripper to install drip tape 30 cm (12 in) below the soil surface. Three rows of drip tape were installed per treatment plot: 1 in the plot center and the other 2 equally spaced 46 cm (18 in) on each side to allow for a more equal distribution of irrigation water. Once the drip tape was installed, the plots were passed over with a double landscape roller seeder (Brillion Farm Equipment, Brillion, Wisconsin) to create a firm, even surface for both the conventional and the mulch-treated plots. We used the subsurface irrigation system during the first crop establishment seasons (2008 and 2009) on both experimental plots and control plots equally. The water was applied at a rate of approximately 2.5 to 5.0 cm (1.0–2.0 in) per week during the months of June and July of the first two seasons, but then discontinued the 3rd growing season.

All plots, at both field sites, were planted during the week of 29 October to 2 November 2007. We planted the control plots using a conventional row crop seeding method without a mulch covering. Seed was drilled to a depth setting of 2.5 cm (1.0 in) using a custom 3-row precision cone seeder (Hege, Wichita, Kansas) with a 0.75 m (2.5 ft) spacing between rows. We planted our experimental plots with a broadcast method using a handheld fertilizer spreader (Earthway, Bristol, Indiana). Immediately after broadcast seeding, 2 chains (1 cm [0.4 in]) were pulled over the soil surface to incorporate the seed. For the mulched treatment, the seed and soil were covered with 5 cm (2 in) of sawdust mulch, then covered with water-permeable N-Sulate fabric, which weighs 50 g/m² (1.5 oz/ft²) and is UV treated (designed not to break down in the presence of ultraviolet light). The sawdust was from C&R Doors (Springville, Utah) and was primarily composed of alder with minor components of other hardwoods.

Average seeding densities per square meter, for both conventionally drilled and broadcast-seeded plots, were 205 seeds (19 seeds/ft²) for silvery lupine, 215 seeds (20 seeds/ft²) for silky lupine, 269 seeds (25 seeds/ft²) for longspur lupine, and 183 seeds (17 seeds/ft²) for hairy bigleaf lupine. We adjusted the above seeding rates for each species to reflect a 100% pure live seed rate.

DATA COLLECTION AND ANALYSIS

To estimate percent emergence of each species, we randomly subsampled 5 areas (1.5 m × 2.3 m [5 ft × 7.5 ft]) within each treatment and control plot at both sites. We counted emerged seedlings and then divided that by the seeding density to determine percent emergence. We visually monitored the plots, several times each week during late March and April 2008, to determine an optimal time to estimate the percentage emergence. We counted the uncovered plots 15 April 2008, and the covered plots 28 April 2008. We found that the uncovered plots were drying out and some of the plants had started to dry up and blow away, thus, the 15 April collection date for the uncovered plots. Covered plots stayed moist until just before 28 April. We permanently removed the N-Sulate fabric and counted the subplot areas, previously described, on 28 April 2008. After the first winter, we did not do subplot sampling to determine our plant establishment values; instead, we counted all living plants

Figure 2. Silky lupine (*Lupinus sericeus*) (A) and silvery lupine (*L. argenteus*) (B) plants from covered treatment during mid-flowering stage of the 2nd growing season.

on 28 May 2009. We considered all living plants as established. Figure 2 shows examples of these established plants.

We made a single harvest of mature seeds of all plants from each plot during the 2nd week of June in both 2009 and 2010, using a custom-built pushcart forage harvester. We dried the seed on tarps and processed them with a Clipper Debearder (AT Ferrell & Company, Saginaw, Michigan), followed by a Carter-Day fractional aspirator (Carter Day International, Minneapolis, Minnesota) to separate seed from plant chaff.

We analyzed the emergence, establishment, and seed production data by treatment, species, site, and block, with year included for seed production, in R 3.0.2 (R Core Team, Vienna, Austria) using a linear mixed model with interactions and Tukey HSD post hoc test for significance with the packages lme4 and lmerTest.

RESULTS

Emergence

We found a significant improvement in emergence with the mulched treatment over the control (conventional) with *P* values of < 0.0001 for all 4 lupine species at both common-garden locations (Figure 3). A higher percent emerged at the Fountain Green WMA farm than at the Snow Field Station (Figure 3). Specifically, they emerged 2.1, 2.4, 3.6, and 9.3 times higher than the control for silky lupine, longspur lupine, hairy bigleaf lupine, and silvery lupine, respectively, at the Fountain Green WMA farm. For the Snow Field Station they emerged 2.9, 3.5, 6.5, and 7.3 times higher for longspur lupine, silky lupine, silvery lupine, and hairy bigleaf lupine, respectively.

Establishment

Like emergence, the establishment of the mulched compared to conventional treatment was significantly greater for silvery, hairy bigleaf, and silky lupine with *P* values of 0.0001, 0.001, and 0.001 respectively (Figure 3) but not for longspur lupine. Shortly after emergence, the longspur lupine plants exhibited severe iron deficiency, expressed as chlorosis, followed by necrosis in the leaves and plant death in most instances. The few plants that grew the 2nd growing season did not survive through the 2nd spring. For silvery lupine and silky lupine, we observed a respective 41.5- and 6.4-fold increase in establishment of the mulched treatment plots compared to the controls at the Fountain Green WMA farm. Furthermore, a mean of 11.9% of the hairy bigleaf lupine survived in the mulch treatment compared to no plants surviving with the control plots at the Fountain Green WMA farm. At the Snow Field Station, we saw a 7-, 23-, and 57-fold increase in establishment for silky lupine, silvery lupine, and hairy bigleaf lupine, respectively, compared to the control plots.

Seed Production

Most native lupine species of the Great Basin are perennials, and they generally produce seed no earlier than the 2nd growing season, and sometimes not until later seasons. Only silvery lupine and silky lupine produced seed during the 2nd and 3rd

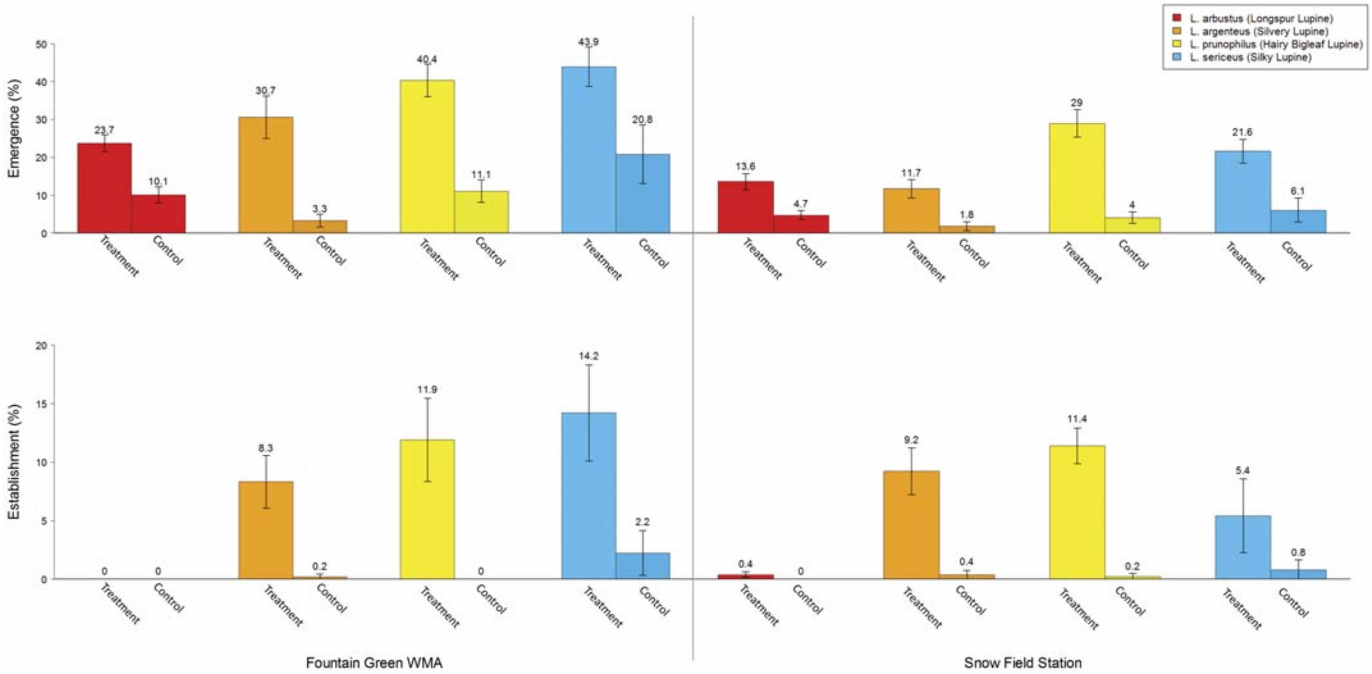

Figure 3. Comparison of the average percent emergence and establishment between the sawdust and N-Sulate fabric (covered treatment) and the conventional control of 4 lupine species at each of the 2 common-garden locations (Fountain Green WMA farm and Snow Field Station). Hairy bigleaf lupine plants in the uncovered plots did not survive the 2nd growing season. No longspur lupine plants from either treatment plots survived the 2nd growing season.

growing seasons (2009 and 2010, respectively). Hairy bigleaf lupine plants emerged and became established (see Figures 2 and 3); however, similar to longspur lupine these plants exhibited serious iron deficiency showing chlorosis and severely stunted growth, at both sites.

The silvery lupine seed yields were significantly greater (*P* value < 0.0001) with the mulched treatment compared to the control at both field sites (Fountain Green WMA and Snow Field Station) and in both years (Figure 4). At the Fountain Green WMA farm, there was a 232-fold increase in seed yield in the mulched plots over the control for 2009 and an 85-fold increase in 2010. At the Snow Field Station, there was a 4.4-fold increase in seed yield of the mulched treatment over the control for silvery lupine in 2009 and an 8.8-fold increase in 2010.

Like silvery lupine, silky lupine seed yields were significantly greater (*P* value < 0.0001) with the mulched treatment compared to the control at both field sites and in both years (Figure 4). At the Fountain Green WMA farm, there was a 4.7-fold increase in seed yield of the mulched plots over the control for 2009 and a 1.7-fold yield increase in the respective yields in 2010. At the Snow Field Station, there was a 1.6-fold yield increase in mulched treatment over the control in 2009 and a 4.9-fold increase in the mulched treatment over the control in 2010.

DISCUSSION

Our results provide the first statistical evidence that N-Sulate fabric improves both emergence and establishment of native forb species. Our results are similar to what has been reported when using N-Sulate fabric and sawdust on tree and shrub plantings, but success has been varied on emergence with forbs (Grubb 2007; Schmal and others 2007; Fleege 2009). When considering the low percent establishment rates for the control plots, it would require many times higher seed density planting (depending on the species) than the mulched treatment (see Figure 3) to have comparable establishment rates. Emergence and establishment data demonstrate the advantage of using N-Sulate fabric and sawdust mulch to improve stand establishment of these lupine species.

When considering the yields from the 2 species from which we were able to collect seed, note that these species have an indeterminate flowering habit (Figure 5). That is, a given plant flowers and fruits over a long period with many stages of development occurring simultaneously from dehisced mature fruit to unopened flowers. Additionally, each plant in this study was a unique genotype. This scenario causes variation in optimum fruiting times for each plant, which is probably not optimal for all the plants in the same plot. The most cost-efficient harvest technique is a single mechanical harvest, opposed to multiple hand harvests throughout the season based on individual fruit ripeness. In our study, we intended to imitate a commercial seed production farm. Thus, the yields reported herein are based on a single harvest. Since both silvery lupine and silky lupine seed mature at essentially the same time, we based our harvest on an estimate of an optimal time point when harvesting would maximize yield across all plots. Albeit, this approach

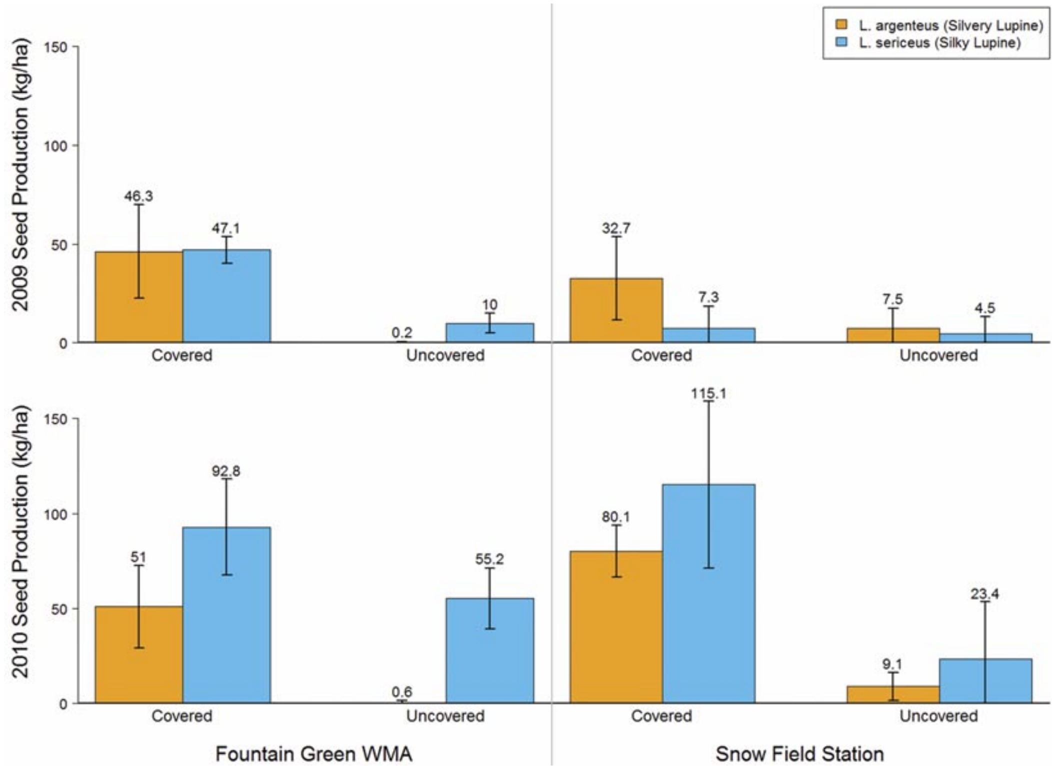

Figure 4. Seed production rates for silvery and silky lupines in the 2nd and 3rd growing seasons. The common garden at Fountain Green WMA farm had higher production the 1st harvesting year, but the common garden at Snow Field Station had higher production the following year.

Figure 5. The indeterminate flowering of a silvery lupine (*Lupinus argenteus*) in its native habitat.

results in a suppressed overall realized yield of mature seed over what could be produced by the plants across the entire growing season.

Plant characteristics that make them well suited for current agricultural technologies for economical seed production and mechanical harvests may include an upright growth habit, being at least 0.3 m (1 ft) tall, determinate flowering, seed retention with non-shattering pods, abundant seed set, annual productivity, easy seed establishment, long-lived, and disease resistant. It is highly probable that if cultivars of these 4 species were selected and developed for the above characteristics, an enhanced seed yield could be realized.

CONCLUSIONS

Greatly improved emergence for longspur lupine, silvery lupine, hairy bigleaf lupine, and silky lupine can be provided by a combination of mulch and woven fabric. Similarly, enhanced establishment can result from this treatment combination for silvery lupine, hairy bigleaf lupine, and silky lupine. This fabric mulch also significantly improved the seed production of silvery lupine and silky lupine. We note that the high price per hectare of N-Sulate fabric may restrict the adoption of this mulch treatment by many growers. Although seed production of improved introduced species is typically much higher than that of natural unimproved germplasm sources, with improved seed and scarification methods along with cultural practices, which might include sowing methods, mulch treatments, disease management, and harvesting, the potential seed production of these lupines may be increased substantially.

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