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Original Research

# Utah Lotus: North American Legume for Rangeland Revegetation in the Southern Great Basin and Colorado Plateau☆,☆☆

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ABSTRACT

Utah lotus (*Lotus utahensis* Ottley) is a North American leguminous forb that may hold promise for rangeland revegetation in the western United States for diversifying planting mixtures, attracting pollinators, providing high-quality forage, and expanding habitats for insects needed by sage-grouse chicks. Fourteen wildland seed collections of Utah lotus originating from Nevada and Utah were assessed for genetic variation of a wide range of phenotypic traits and genetic relationships. Population structure estimates defined by 552 amplified fragment length polymorphism (AFLP) markers identified three primary subgroups within the Utah lotus collections, which corresponded to their geographic origin. Two collections of Utah lotus (LU-5 and LU-20) were among the top-performing collections for the phenotypic traits examined, including dry-matter yield, pod production, number of stems, canopy height, and persistence. No significant Pearson's correlations or canonical correlations were observed among the phenotypic traits and environmental characteristics at the collection sites. Significant correlations were detected between genetic and geographic matrices, and phenotypic and geographic distance matrices ($r = 0.89$, $P = 0.001$ and $r = 0.24$, $P = 0.04$, respectively). Condensed tannin (CT) contents of Utah lotus were between 146 and 199 g $kg^{-1}$ dry matter, which was nearly 10 times higher than CT content of birdsfoot trefoil (*Lotus corniculatus* L.) with 17.3 g $kg^{-1}$ dry matter. Because of our phenotypic and genotypic evaluations, one pooled germplasm source of Utah lotus comprising collections LU-5 and LU-20 could be developed for use in rangeland revegetation in the southern Great Basin and Colorado Plateau.

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## Introduction

Mismanagement of rangelands in the Intermountain Region of the western United States during the late 1800s and early 1900s led to changes in vegetation composition (Fleischner, 1994; Harrison et al., 2003). Changes in species composition and reduced biodiversity contributed to the spread of invasive species such as cheatgrass (*Bromus tectorum* L.), prickly Russian thistle (*Salsola tragus* L.), burningbush (*Bassia scoparia* (L.) A. J. Scott), and tall tumble mustard (*Sisymbrium altisssimum* L.) (Chambers et al., 2007). These invasive, fire-adapted species outcompeted native plant species, increased fuel loads, and exacerbated the frequency of fires (Whisenant, 1990; Brooks, 1999), which in turn encouraged increasingly more frequent devastating wildfires. Revegetation of these degraded rangelands with a biologically diverse suite of plant species (including forbs) is necessary to increase the intervals between fires and stabilize rangeland resources.

Trends in the use of plant materials for rangeland revegetation among public land-management agencies have transitioned from a focus on planting introduced species to planting species native to the western United States (Shaw et al., 2005). Although a number of native grass species are currently available for revegetation uses, there is increased interest in the development of native forb plant materials, particularly for enhancing habitat for pollinators and sage-grouse. North American forbs have the potential to enhance biodiversity, provide important forage, and contribute to soil stabilization. In addition, native

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leguminous forbs can increase soil fertility through biological nitrogen fixation (Rumbaugh, 1990). Germplasm is available for several North American leguminous forb species for revegetation purposes in the western United States, including Utah sweetvetch (*Hedysarum boreale* Nutt.) (Stevens et al., 1994), basalt milkvetch (*Astragalus filipes* Torr. ex A. Gray) (Johnson et al., 2008), western prairie clover (*Dalea ornata* [Douglas ex Hook.] Eaton & J. Wright) (Johnson et al., 2011), and Searls prairie clover (*Dalea searlsiae* [A. Gray] Barneby) (Bhattarai et al., 2011; Johnson et al., 2015). However, a broader range of forb species is necessary for revegetation of diverse rangeland environments of the Intermountain West United States.

Forage legumes sustain animal-based agriculture by providing high-quality forage throughout the growing season (Rumbaugh, 1990). Members of the genus *Lotus* L. are recognized as an important pasture species (Belesky, 1999; Greene, 1999) because of their high digestibility and protein content (Escaray et al., 2012). They also have condensed tannins (CTs), which are of economic interest because they reduce the risk of bloat, improve nutrient absorption, reduce the rate of protein degradation in the rumen (Undersander et al., 1993; Smith and Kelman, 1997), and control intestinal parasites (Novobilisky et al., 2011). The genus *Lotus* has a worldwide distribution of > 100 species that include diploid, tetraploid, and hexaploid taxa (Ito et al., 2000). The two centers with the highest diversity of species within the genus are the Mediterranean Basin and Intermountain Region of the western United States, with 39 species endemic to the continental United States (Kirkbride, 1999). Of the *Lotus* species in the United States, big deervetch (*L. crassifolius* [Benth.] Green), a native to California, Oregon, and Washington, is the only North American *Lotus* species currently used for wildlife and wildland restoration in the western United States (Young-Matthews and Darris, 2011).

Birdsfoot trefoil (*Lotus corniculatus* L.) is an important forage legume from Eurasia and North Africa (Grant and Small, 1996; Kirkbride, 1999; Steiner, 1999). This species is used extensively in pastures of the midwestern and northeastern United States and adjacent portions of Canada, alone or with various forage grasses (Undersander et al., 1993). Utah lotus (*L. utahensis* Ottley) is a North American legume with a native range that includes southern Utah, southeastern Nevada, and the mountains of central Arizona. Because of the successful use of birdsfoot trefoil in mesic areas of North America, the distribution of Utah lotus in semiarid areas of the Intermountain West, and its apparent drought and heat tolerance, Utah lotus has the potential to be a valuable revegetation species in rangelands of the western United States. Other plant traits that have been considered important for species used in revegetation include adaptation to the environmental conditions of the restoration site (Broadhurst et al., 2008; Johnson et al., 2010), excellent seedling establishment and high seed production (Pywell et al., 2003), and favorable biomass and plant height characteristics (Fischer et al., 2013).

The objectives of this study were to 1) make seed collections of Utah lotus throughout its distribution; 2) evaluate these collections for important phenotypic traits (forage and seed production, plant morphology, phenology, survival, forage quality, and CT content) at three common garden sites in northern Utah; and 3) use DNA fingerprinting techniques to evaluate genetic relationships among the collections. This information is critical to determine the potential for possible development of plant materials of Utah lotus for revegetation in the Intermountain West.

## Materials and Methods

### *Plant Materials*

Seed collections of Utah lotus were made in 2012 from 14 sites in eastern Nevada and central to southern Utah (Table 1; Fig. 1). Initial potential collection sites were identified using site data from herbarium specimens for Utah lotus contained in the online database of the Southwest Environmental Information Network (SEINet, 2016). Some of these potential collection sites had only general information about the specific site where the specimen was collected, no longer had Utah lotus plants at the site, did not have an adequate number of plants to make a collection, or plants had dispersed their seed before visiting the site. Herbarium vouchers for the 14 Utah lotus collections were obtained from the Blue Creek common garden in 2014 for species verification. The Intermountain Herbarium at Utah State University in Logan, Utah confirmed the 14 collections to be Utah lotus.

The birdsfoot trefoil cultivar "Norcen" (Miller et al., 1983) was included in our study for comparison with the Utah lotus collections because Norcen has been studied widely for its agronomic and forage quality characteristics. In addition, five collections of scrub lotus (*Lotus wrightii* [A. Gray] Greene) were included in our study to compare Utah lotus with another *Lotus* species native to the western United States.

### *Common Garden Studies*

In January 2013, seeds from each of the 14 Utah lotus collection sites, plus seed of Norcen birdsfoot trefoil and five scrub lotus collections, were germinated and grown in Q-Plugs (International Horticulture Technologies, Hollister, CA) placed within Ray Leach stubby containers (Stuewe and Sons, Corvallis, OR) in a greenhouse at the US Department of Agriculture — Agricultural Research Service Forage and Range Research Laboratory at Logan, Utah, under a 30°C-day–15°C-night temperature regime. A single seedling was grown in each container. Seedlings were treated with a *Lotus*-specific, peat-based rhizobial inoculant mixed with water (Tom Wacek, Lafayette, IN). During May 2013, seedlings were transplanted into cultivated soils at three common gardens in northern Utah (Millville, North Park, and Blue Creek) (see Table 1) in weed barrier fabric. Common garden plots did not receive any supplemental irrigation and were weeded on a weekly basis as needed.

The experimental design at each common garden site was a randomized complete block with five replications. Individual plots consisted of six plants of a single collection within each replication (block). Rows were spaced 0.31 m apart, and plants within rows were spaced 0.31 m apart. A total of 600 plants were transplanted into each common garden site. In addition, Norcen plants were planted around the outside periphery of the common garden plots so that all *Lotus* plants in our study were exposed to competition from other *Lotus* plants. Norcen plants were more vigorous than our native *Lotus* collections. As a result, we found it necessary to cut back the Norcen plants on the periphery of our plots weekly during the 2015 growing season to prevent them from overtaking plants of the native *Lotus* collections.

Plants at each of the three common garden sites established and grew during the 2013 growing season. During the 2014 and 2015 growing seasons, plants at each site were evaluated for survival, date of spring emergence, flowering date, vegetative period (days from emergence to flowering), canopy height, canopy width, longest stem length (LSL), dry-matter yield (DMY), number of stems, pod mass, crude protein (CP), neutral detergent fiber (NDF), and CT content. Pod mass was chosen as a surrogate measure for the number of flowers or seeds per plant because the prolific number of flowers produced by Utah lotus made it impractical to count the number of flowers on each plant. In addition, not all the various collections of Utah lotus matured at the same time, and seeds of Utah lotus can be dispersed considerable distances when pods mature and dehisce. As a result, pod mass was used as a practical indicator of seed production for each plant and reported as pod production.

Spring emergence and flowering dates were recorded weekly beginning the first week of April in 2014 and mid-March in 2015. Spring emergence date was defined as the day at least one stem of an observed plant emerged from the ground. Flowering date was defined as the day the first flower bud opened on any plant in a plot. Survival (persistence) was recorded if a plant was actively growing on the date of DMY harvest. Canopy height, canopy width, and longest stem length were determined at full bloom (Blue Creek on 2 July 2014 and 3 July 2015, Millville on 30 June 2014 and 2 July 2015, and North Park on 1 July 2014 and 1 July 2015). The DMY was harvested when plants reached full pod

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