Calcined Clay Improves Germination of Arid Plant Species[1]

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Abstract

Water conservation efforts in urban landscapes have increased the need for water-wise-plants. A potential source includes multiple native, drought-adapted species. A lack of researched propagation protocols makes commercial production of many species difficult. We examined germination of three native plant species (*Purshia stansburiana*, *Cercocarpus ledifolius*, and *Forestiera pubescens*) in three substrates. Both *P. stansburiana* and *C. ledifolius* are endemic to semiarid areas. *Forestiera pubescens* is found in riparian areas but is drought hardy once established. Stratified seed of each were sown in substrates varying in organic matter (OM) content and water-holding porosity (WHP) characteristics: (1) a commercial germination mix (83% OM); (2) a self-blended combination of a commercial potting soil mixed volumetrically 1:1 with vermiculite (37% OM); and (3) a calcined clay (0% OM). Germination was monitored for 60 days. Percent germination was highest in the calcined clay for each species evaluated (*P. stansburiana*: 63%, *C. ledifolius*: 51% and *F. pubescens*: 83%). These rates were at least 25% greater than the next best medium, the self-blended substrate. The commercial germination blend was the least favorable for germination. These results suggest that the common commercial practice of using germination substrates may not be suited to germinating many species native to arid areas.

Index words: seed germination, water-wise plant production, substrate properties, water conservation, calcined clay.

Species used in this study: Stansbury cliffrose (*Purshia stansburiana* (Torr.) Henricksen); curl-leaf mountain mahogany (*Cercocarpus ledifolius* (Nutt.)); and New Mexico privet (*Forestiera pubescens* (Nutt.)).

Significance to the Nursery Industry

Demand exists in the arid West for drought-adapted landscape plants, and propagation of native plant species provides a source for these needs. Unfortunately, little research on the production of many water-wise plants is available, and these plants have unique growth characteristics that often make their commercial production difficult using traditional production practices. An aspect of these practices is the use of widely available commercial growing substrates, soilless substrates, which may retain excessive water for optimal germination of drought adapted species. Alternatively, there are inexpensive products that have different characteristics, such as calcined clay, that may serve as suitable germination substrates for arid species. In particular, calcined clays are highly porous, making them able to absorb water into pore spaces. However, water not held in pore spaces drains away quickly due to the relatively large particle size. Because of these characteristics, researchers have successfully used calcined clay to grow plants hydroponically, produce bare-root stock and root plant cuttings. Our purposes were to test whether calcined clay can be useful in germinating three selected drought adapted species.

Introduction

The diminishing amount of available water in the arid West has restricted water use in many areas, in particular in urban landscapes (12, 21). As a result, drought-adapted landscape plants are needed to alleviate the strain between water conservation efforts and urban landscape needs. Regionally, there are several native species with the potential for use, but production challenges exist, including a lack of propagation protocols (9, 24). Here we evaluated three such species: Stansbury cliffrose (SC), curl-leaf mountain mahogany (CM) and New Mexico privet (NP). While infrequent, they are sporadically planted in a variety of landscape situations and have anecdotally and visually performed well.

Curl-leaf mountain mahogany (CM): This actinorhizal, rosaceous plant is found in pinion-juniper stands and other similar ecosystems with well-drained soils. It is evergreen, reaches 20 ft high and wide, and is native from Montana to Baja California at elevations from 2,000 to 10,000 ft (19). In landscape situations, it is used as a specimen shrub, in borders and hedges. When regularly clipped, it forms an appearance similar to that of boxwood (*Buxus spp.* L.).

Stansbury cliffrose (SC): This species is also rosaceous, evergreen, actinorhizal and grows to a comparable size of CM but tends to be smaller in stature. It grows at similar elevations and is native from southern Idaho throughout the Southwest from Southern California to New Mexico (5). It has ornamental, creamy-yellow flowers similar in appearance to shrubby cinquefoil (*Dasiphora fruticosa* L.) followed by ornamental seed-heads.

New Mexico privet (NP): New Mexico privet is an oleaceous shrub and reaches 25 feet high and wide. It ranges from California to Oklahoma and is considered a riparian species (8, 10), but is drought hardy once established (22). It produces ornamental spring flowers, and later produces berries attractive to birds (26). The species is used as a hedge plant (15). It is additionally trained into a small ornamental tree. Although it is native to warmer areas, it is cold hardy to at least USDA Zone 4 (30), and is successfully grown in Wyoming and Montana test plots (26, 28).

Much of the existing propagation information concerning CM and SC pertains to breaking seed dormancy to enhance germination. For example, germination of CM can be enhanced by soaking seed in an aerated solution of 1.0 mmole

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KNO_3 and 0.035 mmole GA_3 at 5C (41F) for 3 weeks (31), soaking in a 0.2% solution of KNO_3 at 2C (36F) for 10 weeks (27), or soaking in concentrated sulfuric acid for either 5 or 20 min followed by a 4 hr soak in thiourea [$SC(NH_2)_2$] solution (20). In similar research with SC, Stidham et al. (27), achieved over 95% germination using moist pre-chilling at 2C (36F) for 10 weeks. Likewise, moist stratification at 5C for 2–4 weeks to can break seed dormancy (5). Dormancy can be broken in NP by stratifying seeds in moist sand in a cooler at 3C (38F) for at least 30 days (28). This method is also mentioned in the *Handbook of Seeds on Browse-Shrubs and Forbs* and states that between 50 and 70% germination can be obtained using the afore mentioned method (4).

Few studies, however, examine the impacts of growing substrates on germination, and in each study concerning SC and CM actual seed germination was conducted in a petri-dish, and not in a growing substrate. Additionally, it is unclear if Belcher (4) monitored germination of NP in a petri dish or in a substrate to reach the stated 50–70% germination. This is important because regional growers have observed that many arid native plants including CM and SC often germinate poorly in commercial substrates as compared to the greater rates obtained in petri dishes mentioned previously (20). Researchers germinated Arizona cliffrose (*P.* × *subintegra* (Kearny) Henricksen) seed, a species closely related to SC, in vermiculite and reported 88% germination (2). Beddes and Kratsch (3), additionally found roundleaf buffaloberry (*Shepherdia rotundifolia* Parry), a species native to arid environments in the desert Southwest, germinated best, 66%, in calcined clay and at its lowest rates in the substrates with greater water-holding porosity.

Our objective was to evaluate the impacts of three substrates varying in water-holding porosity levels and organic matter content on seed germination of CM, SC, and NP. The specific substrates were (1) a commercial seed germination substrate, (2) a self-blended combination of a commercial potting soil mixed 1:1 (by vol) with horticulture grade vermiculite; and (3) a calcined clay.

Materials and Methods

Seed germination. All seeds were purchased from Plants of the Southwest (Santa Fe, NM) in November 2010. Seeds were maintained at 22C (72F) at 30% humidity. On March 6, 2011, we sent 1,000 unstratified seeds of each species to the Utah Department of Agriculture and Food seed-testing laboratory (Salt Lake City, UT) for the following quality tests: viability, dormant seed, and germination percentage. On the same day, we placed seeds of the three species into cold-stratification (3C/37F) for 60 days in Rubbermaid™ (Huntsville, NC) brand, sealed food containers (100 × 75 × 5 mm). Prior to stratification, germination paper was cut to fit the bottoms of each container, placed inside and saturated with distilled water. Seeds were placed on top of the germination paper and sealed inside the containers. Seeds were monitored and rinsed with distilled water weekly to minimize water loss. Ninety-six stratified seeds from each of the three species were sown into [20.3 × 40.6 × 5 cm (8 × 16 × 2 in)] seed flats, each filled with one of three substrates. Stansbury cliffrose seed, curl-leaf mountain mahogany and New Mexico privet were all sown to a depth of 0.6 cm (0.25 in). Seed flats were held on a greenhouse mist bench with a 14 hr photoperiod using 400-W, high pressure sodium vapor lamps. Each flat contained 48 individual cells arranged 4 ×12 cells. Sixteen seeds grouped into four rows (one seed per cell) of each species were placed in each flat. Placement of the groups of seed was randomized in each flat. There were 6 flats of each substrate for a total of 18 flats. Each set of 16 seeds was considered an experimental unit (n = 6). The experiment was arranged in a randomized complete block design.

Flats were watered and maintained near container capacity using an automated mist system set to irrigate 30 seconds twice each hour. Mean day/night greenhouse temperatures during the experiment were 22.5/20C (78/68F), with an overall mean temperature of 22C (72F). Mean relative humidity was 52%, and mean daytime photosynthetically active radiation during the experiment was 652 $umol{\cdot}m^{-2}{\cdot}s^{-1}$. Environmental conditions were recorded by a Watchdog™ 2475 weather station (Spectrum Technologies Inc., Plainfield, NY) mounted 1.4 m (4.5 ft) above the ground, 1 m (3.28 ft) adjacent to the flats. Seedling emergence was monitored daily for 60 days.

Substrates. The germination substrates used were: (1) Sunshine™ Mix #3 (Sungro Hort., Bellevue, WA; a germination mix); (2) Sunshine Mix #4 blended 1:1 (by vol) with coarse vermiculite; and (3) calcined clay, PrimeraOne Field Conditioner, (Primera Turf, North Ridgeville, OH; a calcined fuller's earth product). Total porosity, aeration porosity, water-holding capacity and bulk density of the substrates were derived from methodology used by Beddes and Kratsch (3).

Statistics. Germination of each plant species was analyzed separately within a one-way ANOVA, with three levels of substrate (calcined clay, aggregate mix, and germination mix). Additionally, differences, by substrate, in total porosity, aeration porosity, bulk density and water-holding porosity were separately analyzed using one-way ANOVA. Analyses of each were followed by the Tukey post-hoc test to separate differences between treatments when one-way ANOVA was significant. All germination data were arcsine square-root transformed prior to analysis to normalize the distribution of proportional data. Analyses of data were analyzed using SYSTAT (version 13; SPSS, Chicago, IL) software.

Results and Discussion

Calcined clay had the highest germination rates for each of the three species ($P < 0.001$) and increased germination by at least 25% as compared to the self-blended substrate (Table 1). Additionally, seed germination of all species in the calcined clay was approximately equal to the viability rates obtained by the seed testing lab (Table 2), further suggesting that the calcined clay substrate is an optimal germination substrate for these species. Several factors or combinations of factors unique to the calcined clay may account for the greater germination rates. Of the three substrates tested, it is suspected that the calcined clay best matched native conditions that each species germinate in. Specifically with regard to the substrate, characteristics of the native range tend to have low organic matter content and high porosity.

Field soils where CM and SC are native are characteristically shallow and contain less than 2% organic matter (3, 23), and examples exist where relatively high germination rates have been obtained with arid species in substrates containing little to no organic matter. Ibanez and Schupp (13) achieved 71% emergence of CM on seeds placed on top of field soil

Table 1. **Rate and total seed germination of curl-leaf mountain mahogany, Stansbury cliffrose and New Mexico privet in three substrates. Stratified seeds were sewn on May 6, 2011 and germination was recorded daily 60 days (n = 6).**

	Curl-leaf mountain mahogany			Stansbury cliffrose			New Mexico privet		
Substrate	T_{30-90}[z]	T_{50}[y]	Total germination (%)[x]	T_{30-90}	T_{50}	Total germination (%)	T_{30-90}	T_{50}	Total germination (%)
Germination	15	4	13b[w]	49	11	4c	25	31	9c
Self-Mixed	9	2	24b	17	6	38b	13	25	49b
Calcined clay	1	1	51a	15	4	63a	21	13	83a

[z]Estimated number of days from 30–90% of the measured germination rate.

[y]Estimated number of days to reach 50% of the measured germination rate.

[x]Germination is calculated as a percentage of the total seed sewn and is rounded to the nearest whole number.

[w]Means separation within germination columns by Tukey's HSD at $P < 0.05$.

collected from where the species grows. Baggs and Maschinski (2) achieved 88% germination with *P. subintegra* seed in vermiculite, a substrate containing no organic matter. These studies show that substrates containing little to no organic matter can be useful in maximizing germination rates of certain arid species.

The lower germination rates of the species in the germination and self-blended substrates are most likely due to the substrates' organic matter content, where the organic matter particle size is smaller than non-organic components. The smaller particle size of the germination mix and self-blended substrate may retain more water compared to the calcined clay that has a larger particle size. Substrates with a greater percentage of larger particles retain less water (1). Argo (1), states that the total porosity of an average organic matter based growing substrate is often near 85%, and that an accepted standard for aeration porosity at container capacity is as low as 15%. The commercial germination substrate used in this work very closely matched these parameters but resulted in the lowest number of germinated seeds among all species (Tables 1 and 3).

Organic matter content also likely reduced water evaporation rates from the germination substrate and self-blended substrate, because water evaporates at slower rates from substrates containing organic matter as compared to certain inorganic substrates. Calonje et al. (7), compared germination rates of three *Zamia* species in three substrates including one substrate containing organic matter, and the other two inorganic substrates being sand and Turface MVP®, a calcined clay product. The Turface MVP® had similar properties to the calcined clay used in our work (Table 3). These included bulk density (0.71 $g \cdot cm^{-3}$), aeration porosity (16.3%), water holding-porosity (40.3%) and total porosity (56.7%). The authors found that water evaporated more quickly from the Turface MVP® as compared to the substrate containing organic matter. The authors reasoned that this was a likely result of the highly porous nature of the Turface MVP® and the portion of course particles that it contained.

Similarly it is expected that water evaporated more quickly from the calcined clay as compared to the other substrates used in our work. Further, the calcined clay had reduced water-holding porosity and increased aeration porosity as compared to the other substrates ($P < 0.001$ and $P = 0.006$ respectively; Table 2). This lower water holding porosity is most likely due to the calcined clay's particle size that ranges from an estimated 1.0 to 3.0 mm (0.04 to 0.1 in), where substrate particles greater than 1.0 mm (0.04 in) have increased aeration porosity as compared to those of smaller size (1, 6, 18). Beside the lack of organic matter, the calcined clay's reduced-water holding porosity is also due to its greater bulk density, because total porosity is inversely proportional to bulk density (1). Others have found similar results concerning calcined clay. Kang et al. (16), tested a calcined clay and other inorganic growing substrate components. The calcined clay they tested had higher bulk density and 'air volume' but 'low water volume' as compared to the other tested substrates including perlite and Rockwool. Since the various substrates in our study were maintained near container capacity, the calcined clay apparently retained sufficient but not excessive moisture for seeds to imbibe water and maintain adequate moisture levels to germinate at greater rates than the other two substrates. Additionally, due to the large particle size of the calcined clay, what water the substrate retained was most likely in capillary pore space. Here, non-capillary pore space that seeds were exposed to was mostly air filled at container capacity (3).

Not only are final germination rates (Table 1) in the various substrates important to growers, but germination patterns (Fig. 1) over time are additionally useful in managing plant propagation for the end-user and as it relates to business

Table 2. **Results of seed quality testing of curl-leaf mountain mahogany, Stansbury cliffrose and New Mexico privet seed submitted to the Utah Department of Agriculture and Food testing laboratory on March 6, 2011. One thousand seeds of each species were submitted.**

	Seed quality			
Species	Tetrazolium (TZ) viability (%)	Dormant seed (%)	Total viable seed (%)[z]	Germination (%)
Stansbury cliffrose	56	18	67	49
Curl-leaf mountain mahogany	63	4	47	43
New Mexico privet	97	50	91	41

[z]Total seed viable was determined after germination testing and is a combination of germinated and dormant seed and was performed as a more exact test of viable seed as compared to the estimated viability derived from tetrazolium testing.

Table 3. **Relative differences in pore-space distribution, organic matter content and bulk density the germination substrate, self-mixed substrate and calcined clay substrate used for seed germination of curl-leaf mountain mahogany, Stansbury cliffrose and New Mexico privet (n = 3).**

	Substrate properties				
Substrate	Total porosity (%)	Water holding porosity (%)	Aeration porosity (%)	Bulk density ($g \cdot cm^{-3}$)	Organic matter[y] (%)
Germination substrate	83c[z]	68c	15b	0.16b	83
Self-Blended substrate	74b	56b	18ab	0.17b	42
Calcined clay	61a	40a	22a	0.70a	0

[z]Means separation within columns by Tukey's HSD at $P < 0.05$. Numbers within these columns rounded to the nearest whole number.

[y]Percent organic matter was derived from the manufactures labels and not statistically analyzed.

management. Of note, CM reached 90% germination (of the seeds that germinated over the course of the experiment) in the calcined clay on day 1 and SC on day 22. New Mexico Privet did not reach 90% germination until day 35. One factor that may explain why CM germinated so early in the calcined clay includes that certain species endemic to course soils tend to germinate more quickly when seeded in a coarsely textured substrate. Schutz et al. (25), worked with four separate *Eucalyptus* species, two endemic to sandy soil and the others to loamy soil. The authors seeded all species in both sand and a loamy soil substrate and noted that the *Eucalyptus* native to sandy soil germinated at faster rates in the sand than they did in the loamy soil, but the loamy soil species germinated at equal rates in both substrates.

In our study, New Mexico privet did not show a similar germination pattern to CM. However, it is noteworthy, that germination of this riparian NP was maximized in the calcined clay in contrast to another riparian species examined by Beddes and Kratsch (3), silver buffaloberry [*Shepherdia argentea* (Pursh.) Nutt.]. The authors found that silver buffaloberry germinated at equal rates, varying from 42–54%, in all substrates, that included a commercial germination substrate; a self-blended substrate containing a mix of perlite, a calcined clay and sand; and a calcined clay. The substrates they used varied in water holding capacity similarly to ours. The difference between NP germination in this study and silver buffaloberry may be explained by the variability in soil moisture content in different areas of riparian zones where these species reside. The NRCS states that riparian areas encompass ecosystems occurring along water courses or water bodies different from surrounding lands due to unique soil and plant characteristics that are heavily influenced by free unbound water in the soil, and occupy transitional areas between the terrestrial (dry) and aquatic (wet) ecosystems (29). New Mexico privet is listed as riparian but as being upland obligate, which is defined as rarely being a hydrophyte and almost always in uplands portion of riparian zones (29). Conversely, silver buffaloberry is apparently more tolerant of permanently moist soil where, in the western United States, it is endemic along the edges of stream and river banks; the shorelines of ponds and lakes; and other areas with permanently moist soil (11). Where these species often occupy different zones within riparian ecosystems, it is not surprising that the seeds of NP did not germinate well in the substrates with greater water holding capacity.

Non-germinated seeds used in this work were not collected post experiment for viability testing. However, we suspect that many seeds were detrimentally impacted by soil microorganisms in the self-blended and germination substrates, where excessive irrigation can lead to greater

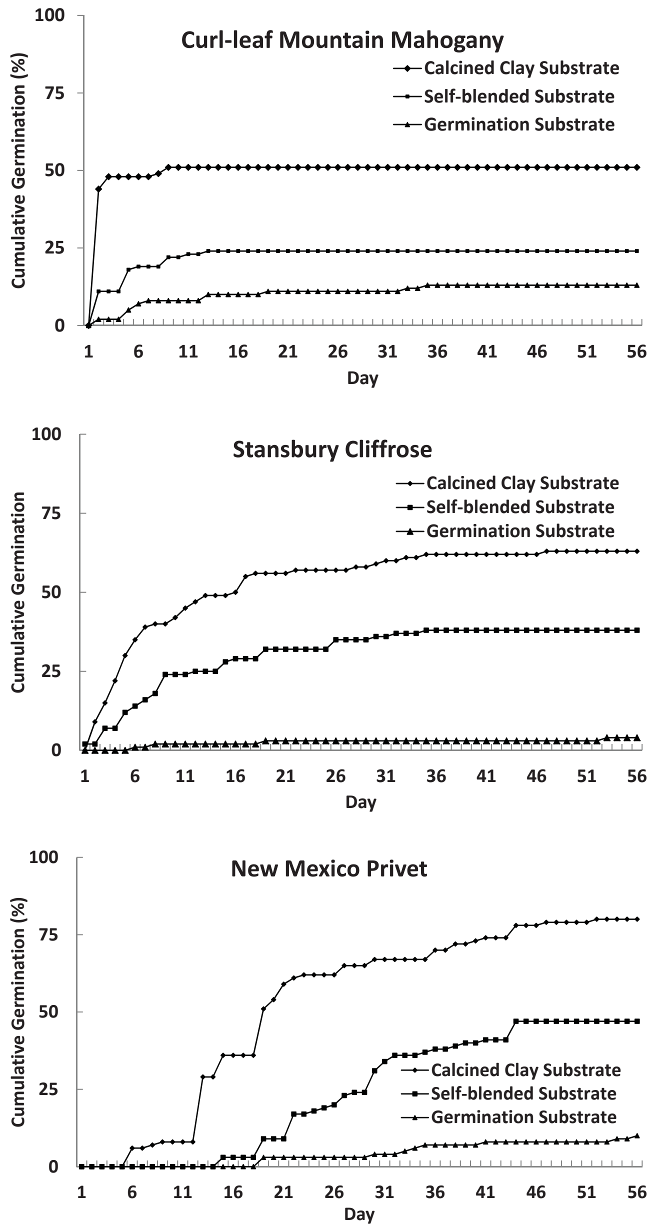

Fig. 1. **Cumulative germination percentage of curl-leaf mountain mahogany, Stansbury cliffrose and New Mexico privet exposed to three substrate treatments including a calcined clay substrate, a self-blended substrate and a commercial germination substrate (n = 6). Germination was monitored for 60 days, no seeds germinated after day 56.**

incidences of disease (17). Beddes and Kratsch (3), suspected water-holding capacity and organic matter content caused low germination rates of roundleaf buffaloberry in substrates they worked with as compared to the calcined clay. They stated that the calcined clay most likely buffered the seed against detrimental effects of frequent irrigation. The USDA NRCS Plants Database further lists all three species as being anaerobic intolerant, which suggests that seed could be detrimentally impacted in substrates with greater water-holding porosities.

Increased availability of ornamental, drought-adapted species is an important aspect of resource conservation. Unfortunately little production information exists concerning many of these species. We have shown that, of the substrates we tested, calcined clay optimized germination. Our data suggest this may be primarily due to the increased water-holding porosity of the germination substrate and self-mixed substrate created by their organic matter content.

Further testing is needed, but we additionally expect that other similar commercially available organic matter rich substrates are detrimental to germination of these and other species endemic to arid areas with soils low in organic matter. Beddes and Kratsch (3) stated similar conclusions, and other examples exist where researchers recommend using growing substrates better suited to the particular crop being grown. One includes Bunt (6), recommending rhododendrons be produced in sharply drained soil due to winter root-rot being common in the species in substrates with excessive water-holding porosities.

The method we used to germinate seeds is easily replicated by commercial growers as all materials are readily available and inexpensive. However, further research is justified in pinpointing the specific influences of organic matter, substrate pore size and soil microorganisms on germination of arid species, and into the usefulness and practicality of various calcined clay products available. A reason given as to why calcined clays have not been more widely used in the industry is due to their high bulk density makes them difficult to handle (14). However, potentially useful calcined clays with lower bulk densities currently exist that deserve trialing.

Literature Cited

1. Argo, W. 1998. Root medium physical properties. HortTechnology 8:481–485.

2. Baggs, J. and J. Maschinski. 2001. From the greenhouse to the field: cultivation requirements of Arizona cliffrose (*Purshia subintegra*). Southwestern Rare and Endangered Plants: Proc. of the Third Conference 23:176–185.

3. Beddes, T. and H. Kratsch. 2009. Seed germination of roundleaf buffaloberry (*Shepherdia rotundifolia*) and silver buffaloberry (*Shepherdia argentea*) in three substrates. J. Environ. Hort. 27:129–133.

4. Belcher, E. 1978. Handbook on seeds of browse-shrubs and forbs. USDA Forest Service, Atlanta, GA. p. 62.

5. Booth, T., S. Meyer, and N. Shaw. 2012. *Purshia* DC. Ex Poir. bitterbrush, cliffrose. Woody Plants Seed Manual. USDA, Dry Branch, GA. p. 381–384.

6. Bunt, A. 1983. Physical properties of mixtures of peats and minerals on different particle size and bulk density of potting substates. Acta. Hortic. 150:143–153.

7. Calonje, C., C. Husby, and M. Calonje. 2010. Germination and early seedling growth of rare *Zamia* spp. in organic and inorganic substrates: Advancing in situ conservation horticulture. HortScience 45:679–683.

8. Cusack, C. and A. Fernald. Effects of acequias and ground water levels on riparian vegetation, evapotranspiration, and restoration. New Mexico Water Research Institute. Las Cruces NM. Accessed June 13, 2012. http://wrri.nmsu.edu/research/rfp/studentgrants07/reports/Cusack.pdf.

9. Dunne, R. and C. Dunne. 2002. Potential for expanded production of native rangeland seed in Western North America. Native Plants J. 3:34–37.

10. Dahm, C., J. Cleverly, J. Allred-Coodard, J. Thibault, D. McDonell, and D. Gilroy. 2002. Evapotranspiration at the land/water interface in a semi-arid drainage basin. Freshwater Biol. 47:831–843.

11. Esser, L. 1995. Shepherdia argentea: Fire effects information system. USDA Forest Service Rocky Mountain Research Station Fire Science Laboratory. Accessed July 27, 2012. http://www.fs.fed.us/database/feis/.

12. Hanack, E. and M. Brown. 2008. Linking housing growth to water supply. New planning frontiers in the American West. J. Amer. Plan. Assoc. 72:154–166.

13. Ibanez, I. and E.W. Schupp. 2002. Effects of litter, soil surface conditions, and microhabitat on *Cercocarpus ledifolius* Nutt. seedling emergence and establishment. J. Arid Environ. 52:209–221.

14. Ingram, L., R. Henely, and T. Yeager. 1993. Growth media for container grown plants. Bulletin 241. U of Florida Ext. Serv. Gainsville. FL.

15. Johnson, E. 1953. Ornamental hedges for the Southern Great Plains. United States Department of Agriculture. Washington DC. Farmers Bulletin #255.

16. Kang, J., H. Lee, and H. Kim. 2004. Physical and chemical properties of inorganic horticultural substrates used in Korea. Acta. Hortic. 644:237–241.

17. Katan, J. 2000. Physical and cultural methods for the management of soil-borne pathogens. Crop Protection 19:725–731.

18. Kim, B., G. Lee, C. Park, and H. Jeon. Modification of calcined-clay and its physical properties for use as a subsidiary material for growing media. J. Plant Nutr. 33:654–669.

19. Kitchen, S. 2012. Cercocarpus Kunth mountain-mahogany. Woody Plants Seed Manual. USDA, Dry Branch, GA. p. 381–384.

20. Liacos, L. and E. Nord. 1961. Curlleaf Cercocarpus seed dormancy yields to acid and thiourea. J. Range Management 14:17–20.

21. Martin, C., K. Petersen, and L. Stabler. 2003. Residential landscaping in Pheonix, Arizona, U.S.: Practices and preferences relative to covenants, codes and restrictions. J. Arborculture 29:9–17.

22. Mee, W., J. Barnes, R. Kjelgren, R. Sutton, T. Cerny, and C. Johnson. 2003. Waterwise: Native Plants for Intermountain Landscapes. USU Press, Logan, UT.

23. Pashke, M. 1997. Actinorhizal plants in rangelands on the western United States. J. Range Manage. 50:62–72.

24. Potts, L., M. Roll, and S. Wallner. 2002. Colorado native plant survey — Voices of the green industry. Native Plants J. 3:121–125.

25. Schutz, W., P. Millberg, and B. Lamont. 2002. Germination requirements and seedling responses to water availability and soil type in four Eucalypt species. Acta. Oecol. Int. J. Ecol. 23:23–30.

26. Scianna, J. and R. Hybner. 2009. Plant materials technical note: Stretchberry *Forestiera pubescens*: A shrub for potential conservation applications in Montana and Wyoming. USDA NRCS, Bridger, MT. Accessed online June 3, 2012. http://www.plant-materials.nrcs.usda.gov/pubs/mtpmctn9085.pdf.

27. Stidham, N., R. Ahring, J. Powell, and L. Claypool. 1980. Chemical scarification, moist prechilling and thiourea effects on germination of 18 species. J. Range Manage. 33:115–118.

28. USDA Soil Conservation Service. 1978. Notice of the naming and release of 'Jemez' New Mexico Forestiera for use in resource conservation plantings. Accessed online June 10, 2012. http://www.plant-materials.nrcs.usda.gov/pubs/nmpmcrnfone3jeme.pdf.

29. USDA NRCS. 2012. Riparian and Floodplain Management Webpage. Bozeman, MT. Accessed June 13, 2012. http://www.mt.nrcs.usda.gov/technical/ecs/water/setbacks/.

30. USDA NRCS Plants Database. 2012. Forestiera pubescens. Accessed June 12, 2012. http://plants.usda.gov/java/profile?symbol=FOPUP.

31. Young, J., R. Evans, and D. Neal. 1978. Treatment of curlleaf Cercocarpus seeds to enhance germination. J. Range Manage. 42:614–620.