Figure 1. Gooseberry-leaf globemallow. Photo by Eric Gardener

Optimal seeding depth of five forb species from the Great Basin

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ABSTRACT

Use of forbs in revegetation projects in the Great Basin is limited due to high seed cost and insufficient understanding of their germination and establishment requirements. We tested the effects of seeding depth from 0 to 25.4 mm (1 in) on emergence and survival in clay and sandy loam soils of 5 ecologically important forbs. Significantly less emergence occurred of gooseberry-leaf globemallow (*Sphaeralcea grossulariifolia* (Hook. & Arn.) Rydb. [Malvaceae]) without a 3.2 mm covering of soil in both soil textures (14% and 19% reductions, respectively). Mountain dandelion (*Agoseris glauca* (Pursh) Raf. [Asteraceae]), Utah milkvetch (*Astragalus utahensis* (Torr.) Torr. & A. Gray [Fabaceae]), and tapertip hawksbeard (*Crepis acuminata* Nutt. [Asteraceae]) had greatest emergence on the soil surface and decreased at greater depths. Scarlet globemallow (*Sphaeralcea coccinea* (Nutt.) Rydb. [Malvaceae]) and *S. grossulariifolia* had significantly greater survival in the sand loam (71% and 87%) than in the clay soil (32% and 52%). Survival of *A. utahensis* and *C. acuminata* decreased significantly with surface seeding in the sandy loam soil. Seeding depth did not significantly impact survival of *A. glauca*. Seeding at 25.4 mm (1 in) reduced emergence or survival for all species. Maximum emergence and survival occurred at shallower seeding depths in the clay loam for most species. Based on our results for these forbs, we recommend a seeding depth of 3.2 mm (0.13 in) in clay soil and 6.4 mm (0.26 in) for sandy loam soil.

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KEY WORDS
native forbs, seeding depth, emergence, survival, Asteraceae, Fabaceae, Malvaceae, *Sphaeralcea*

NOMENCLATURE
USDA NRCS (2007)

Native forbs increase plant community diversity, health, resilience, and resistance to disturbance (Symstad and Tilman 2001; Welch 2004; Pokorny and others 2005; Walker and Shaw 2005). Forbs hinder invasion of nonnative plant species by stabilizing disturbed areas, reducing erosion, and increasing competition for resources (Anderson and Inouye 2001; Brown and Bugg 2001; Dukes 2001; Walker and Shaw 2005). Resistance to fire occurs as many forbs remain green longer than grasses (Walker and Shaw 2005). Nitrogen-fixing forbs increase soil nitrogen (Walker and Shaw 2005). Many non-leguminous forbs enrich wildlife diet in spring and summer months by containing higher crude protein and phosphorous than do grasses and shrubs (McArthur 1988; Welch 2004). Despite their importance for wildlife and habitat, the use of native forbs in seed mixes has been limited in revegetation projects because of high seed cost, limited availability, poor establishment, and lack of knowledge of their germination characteristics (Willoughby and others 1998; Monsen and Shaw 2000; Van Epps and Stevens 2004; Walker and Shaw 2005).

Correct seeding depth is crucial to germination, emergence, and seedling establishment (Ries and Hofmann 1995; Benvenuti and others 2001; Grundy and others 2003; Benvenuti 2003; Sanderson and Elwinger 2004). On one hand, high bulk densities of soils at lower depths can maintain inadequate temperatures and can reduce gas diffusion and light penetration to levels that inhibit germination and cause germinable seeds to re-enter dormancy (Benvenuti 2003; Jorgensen and Wilson 2004; Reid and Van Acker 2005; Peachey and Mallory-Smith 2007). In addition, seeds germinating too deeply within the soil profile either exhaust their resources before seedlings emerge or seedlings do not have enough resources to establish after emergence (Froud-Williams and others 1984; Davis and Renner 2007). On the other hand, low germination and high seedling mortality can be caused by seeding at shallow depths (Plummer and others 1968). The range of seeding depths for optimal germination, emergence, and establishment is species specific (Boyd and Van Acker 2003). Research determining optimal seeding depths has focused on grasses, shrubs, weeds, and crops, but little is known about seeding depth requirements of native forbs.

Generalities, such as planting smaller-seeded species no deeper than 3.2 mm and larger seeds no deeper than 12.7 mm, have been recommended (Plummer and others 1968; Stevens and others 1996). Jordan (1981) proposed an average maximum depth of 6.4 mm for small-seeded species (more than one million seeds per pound) and about 12.7 to 19.1 mm for larger-seeded species. Others suggest most seeds should be covered with a soil layer 2.5 to 3 times the thickness of cleaned seeds (Monsen and Stevens 2004). When forbs are included in seed mixes of large-scale revegetation projects and are drill-seeded (6.4 to 12.7 mm) or broadcasted (0 mm) in concert with grasses, few forbs are established (Roundy and Call 1988). Planting forbs with standard farming equipment to a depth of 50 to 100 mm resulted in poor seedling establishment (Goodrich and others 2001). Recommended seeding depths for several species (Plummer and others 1968; Stevens and others 1985; Stevens and others 1996; Jensen and others 1999; USDA 2007) have been achieved through trial and error in revegetation projects over a multitude of climatic and topographical conditions but have not been confirmed by scientific testing.

This study investigated emergence of 5 native forb species at seeding depths from 0 to 25.4 mm (1.0 in) in sandy loam and clay loam soils.

MATERIALS AND METHODS

Seeds for mountain dandelion (*Agoseris glauca* (Pursh) Raf. [Asteraceae]), Utah milkvetch (*Astragalus utahensis* (Torr.) Torr. & A. Gray [Fabaceae]), tapertip hawksbeard (*Crepis acuminata* Nutt. [Asteraceae]), scarlet globemallow (*Sphaeralcea coccinea* (Nutt.) Rydb. [Malvaceae]), and goose-

TABLE 1

Seed collection date, site, and site elevation of each species.

Species	Collection Date	Collection Site	Collection Elevation m (ft)
Agoseris glauca	Jun 2003	Box Elder County, Utah	1615 (5330)
Astragalus utahensis	Jun 2003	Utah County, Utah	1483 (4894)
Crepis acuminata	Jul 2003	Lander County, Nevada	1570 (5181)
Sphaeralcea coccinae	Jun 2003	Carbon County, Utah	1524 (5029)
Sphaeralcea grossulariifolia	Jun 2003	San Juan County, Utah	1579 (5211)

berry-leaf globemallow (*S. grossulariifolia* (Hook. & Arn.) Rydb.) were obtained from the USDA Forest Service Shrub Laboratory in Provo, Utah (Table 1; Figure 1 and 2). Clay loam (sand 35%, clay 30%, silt 36%) and sandy loam (sand 69%, clay 13%, silt 19%) soils were collected from the Brigham Young University Agricultural Station in Spanish Fork, Utah. Soils were selected to reflect common soil textures in the Great Basin.

Seeds were treated to maximize germination. The 2 species of *Sphaeralcea* were acid-scarified using 1 Nm H_2SO_4(Roth and others 1987). *Astragalus utahensis* seeds were mechanically scarified by nicking the testa with a razor (Townsend and McGinnies 1972). Cold-treated seeds were planted in plastic flats at the seeding depths 0, 3.2, 6.4, 12.7, and 25.4 mm and incubated at 15 °C (59 °F) for about 4 wk. If emergence was observed before the 4-wk period ended, flats were placed in a greenhouse and emergence was recorded.

Each species was planted in a split-plot design in #1020 (30.5 x 61 x 5.1 cm) germination flats with 2 to 6 replicates, depending on seed availability (Table 2). Soil flats contained 5 evenly spaced rows randomly assigned to one of the 5 seeding depths. Depths below 25.4 mm were not investigated because other studies reported that emergence of many forb species decreases exponentially at seeding depths > 20 mm (Benvenuti and others 2001; Penny and Neal 2003; Wilson and others 2006; Davis and Renner 2007). Rows were planted with 20 or 30 seeds, depending on seed availability for each species (Table 2). The study was replicated between 2003 and 2005 to obtain 2 or 3 trials for each species in soil texture with statistically significant emergence (Table 2). Trials with limited emergence were removed from the data set.

Planting Procedure

A 25-mm layer of soil was placed in the bottom of each flat. Seeds were placed in the row designated for the 25.4 mm treatment depth. Rectangular wooden dowels (6.3 mm thick) were

CONVERSIONS

3.2 mm	0.125 in
6.4 mm	0.25 in
12.7 mm	0.5 in
19.1 mm	0.75 in
20 mm	0.8 in
25.4 mm	1.0 in
40 mm	1.6 in
50 mm	2.0 in
100 mm	4.0 in
5.1 cm	2 in
30.5 cm	12 in
61 cm	24 in

TABLE 2

For each species: number of seeds sown per seeding depth in a single flat and number of flats planted in each soil type during the trial replications included in analysis.

	TRIAL								
	1			2			3		
	Seeds/	Blocks		Seeds/	Blocks		Seeds/	Blocks	
Species	row	Clay	Sand	row	Clay	Sand	row	Clay	Sand
Agoseris glauca	20	3	—	20	5	5	20	5	5
Astragalus utahensis	20	5	5	20	5	5	20	5	—
Crepis acuminata	20	5	5	20	3	3			
Sphaeralcea coccinae	20	5	2	20	5	5	20	5	—
Sphaeralcea grossulariifolia	30	4	6	20	5	5	20	5	—

laid down in the flat, and soil was added until level with the dowel. The dowels were removed and the indentation filled with soil, after which the 12.7 mm row was planted. The process was repeated with dowels of appropriate thickness (12.7, 6.3, 3.2, and lastly 0 mm) to obtain the designated seeding depths. Soil layers were slightly compressed with a mason's trowel after each soil layer was added for a firm seedbed and to ensure that seeds did not move. Flats were kept moist and placed in a greenhouse with a temperature of about 27 °C (81 °F). Emergent seedlings were recorded every 3 d during a 45-d period or until emergence ceased. Emergence was defined as cotyledons being pushed above the soil surface or, in the case of the 0 mm depth, a root entering the soil (Boyd and Van Acker 2003). Percentage survival was calculated using seedling density at day 45 (or last recorded density if emergence stopped before day 45) divided by maximum emergence.

Statistical Analysis

Maximum percentage emergence was calculated for each row. Percentage values were tested for normality using the Shapiro-Wilk statistic in SAS (PROC UNIVARIATE; SAS Institute Inc 2004). The ArcSIN square root transformation was used to normalize all data. All data were analyzed in SAS PROC MIXED (SAS Institute Inc 2004). Trial, soil type, and seeding depth effects on emergence were analyzed with flat, soil x flat, and soil x flat x depth designated as random effects. The trial x depth interaction was not significant for any species, so trial replications were combined with flat replications to balance the data set within species. Effects of seeding depth, soil type, and their interaction on seedling survival were analyzed using the same random effects model as used for analyzing emergence. Trial, seeding depth, soil type, and their interactions were considered significant at $P \leq 0.10$.

RESULTS

Emergence

Seeding Depth

Agoseris glauca and *C. acuminata* had greatest emergence at 0 mm to 6.4 mm seeding depths (Figure 2). Emergence of both *Sphaeralcea* species was greater with a 3.2 mm soil covering (*S. coccinea* $P = 0.007$; *S. grossulariifolia* $P < 0.001$) (Figure 2). *Astragalus utahensis* emergence was significantly reduced at the 25.4 mm seeding depth ($P = 0.002$) (Figure 2).

Agoseris glauca and *A. utahensis* emergence in the clay loam soil gradually decreased with increasing seeding depth (Figure 2). Emergence of *A. glauca* and *A. utahensis* at 25.4 mm depth was significantly less ($P < 0.001$ and $P = 0.002$) than at the 0 mm and 3.2 mm depths. Emergence of *C. acuminata* was greatest at the surface and 3.2 mm depth in the clay soil. Emergence of *S. coccinea* and *S. grossulariifolia* in clay loam soil tended to increase with depth to 6.4 mm (Figure 2).

Crepis acuminata emergence in sandy loam soil (Figure 2) was greatest when seeded at 6.4 mm or shallower. *Agoseris glauca* emergence was more adversely affected by deeper seeding depths in the sandy loam soil than in the clay loam soil (Figure 2). *Astragalus utahensis* emergence tended to decrease with increasing planting depth as it did in the clay loam soil (Figure 2). Emergence of *S. grossulariifolia* with a covering of

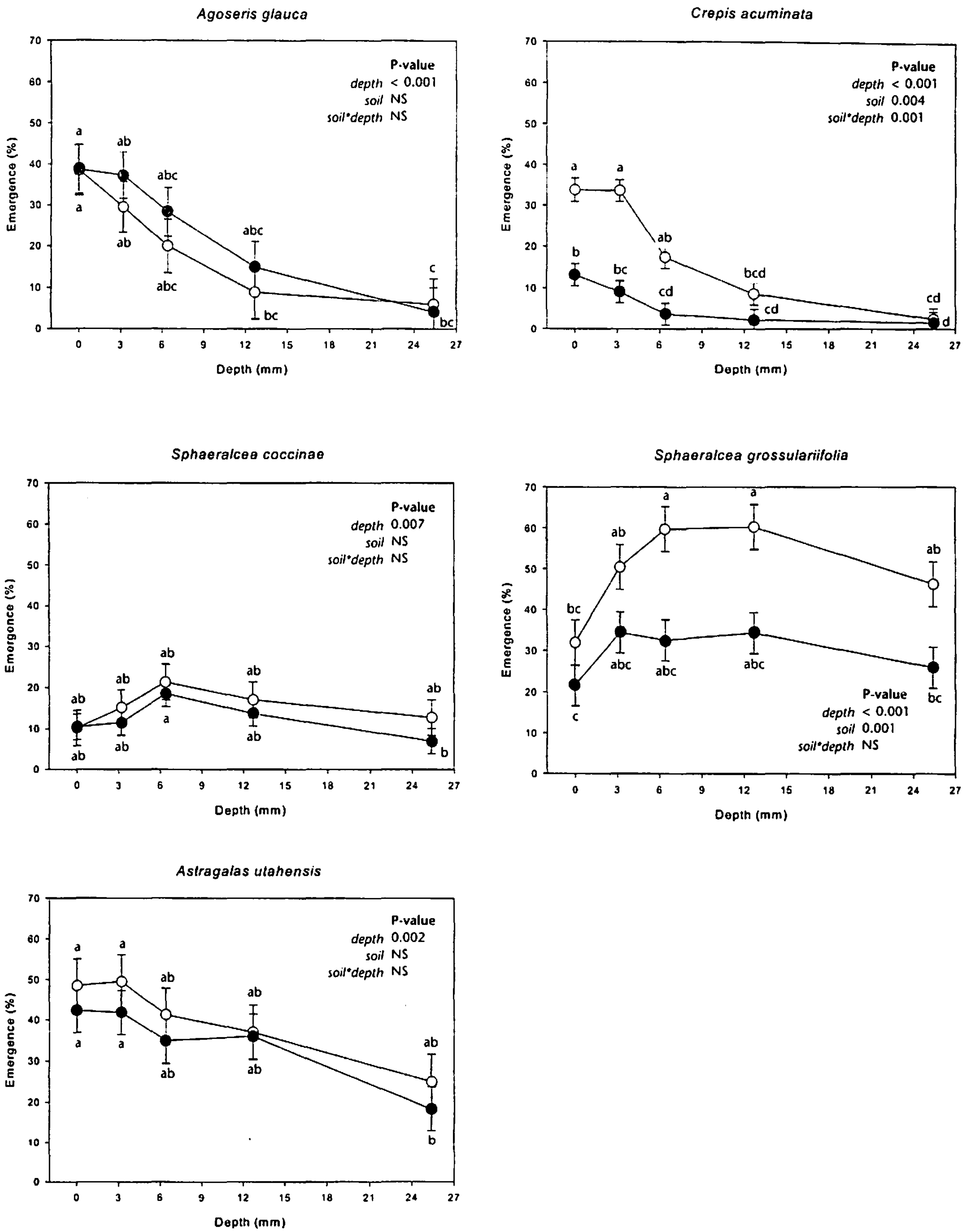

Figure 2. Maximum emergence of forbs in clay loam (black circles) and sandy loam (white circles) soils. Significance of depth, soil, and their interaction on maximum emergence is reported. Significance is defined as $P \leq 0.10$.

3.2 mm of sandy loam soil was significantly greater than emergence with surface seeding ($P < 0.001$). This trend was also observed for *S. coccinea.*

Soil Type

Less emergence of *C. acuminata* ($P = 0.004$) and *S. grossulariifolia* ($P = 0.001$) occurred in the clay loam soil. *Astragalus utahensis* and *S. coccinea* emergence also tended to decrease in the clay loam soil. *Agoseris glauca* was the only species with greater emergence in clay loam soil than in the sandy loam soil.

Survival

Seeding Depth

Astragalus utahensis and *C. acuminata* survival was significantly lower with surface seeding in the sandy loam soil ($P = 0.047$ and $P = 0.017$) (Figure 3). Seeding depth did not have a significant impact on the survival of *A. glauca* seedlings. *Sphaeralcea coccinea* seedling survival was greatest at the 6.4 mm seeding depth in both soils, while *S. grossulariifolia* had high survival at all seeding depths (Figure 3).

Soil Type

Sphaeralcea coccinea ($P = 0.009$) and *S. grossulariifolia* ($P = 0.024$) had significantly greater survival in the sandy loam soil (71% and 87%) than in the clay loam soil type (32% and 52%) (Figure 3). Survival of *A. glauca* was lower in the sandy loam soil than in the clay loam soil.

DISCUSSION

Improved emergence of 4 species seeded in sandy soils compared with seeding in clay soils is consistent with other studies (Reuss and others 2001; Benvenuti 2003). Higher bulk densities of clay soils can inhibit germination by reducing gas exchange around seeds. In high density soils, a hypoxic and toxic atmosphere forms around germinating seeds when O_2 is consumed and ethanol is released in breakdown of the testa (Benvenuti and Macchia 1995; Benvenuti 2003). Inhibition of seed germination because of poor gas exchange is the main cause of decreased emergence at greater seeding depths (Benvenuti and others 2001; Benvenuti 2003). Mechanical resistance caused by soil crusting can also prevent emergence (Shiel and Yuniwo 1993; Nabi and others 2001) because high bulk densities in crusted or clay-rich soils increase the resistance to roots and cotyledons of seedlings penetrating the soil. We found it surprising that *A. glauca* had greater emergence in the clay loam soil at all seeding depths and believe this should be investigated further.

In addition to increasing clay concentrations, the bulk density of soil increases with depth in all soil textures. Soil bulk density increases significantly 20 to 40 mm below the soil surface (Reid and Van Acker 2005). Other studies of seeding depth effects on forbs indicate optimal (greenhouse) conditions favor emergence from a wider and deeper range of seeding depths than in the field (Grundy and others 2003). This phenomenon may explain why no single depth yielded significantly greater emergence, but rather, trends of increasing emergence were observed. Seeding at greater depths would likely have more negative consequences on seedling emergence under field conditions. A slight covering of seeds with soil appears necessary for maximum emergence of *S. grossulariifolia* and *S. coccinea* regardless of soil texture. This distinct increase was not observed in the other species.

Reduced germination and decreased seedling survival with burial of seeds has been directly related to increasing clay content and is inversely proportional to sand content for other forb species (Benvenuti 2003; Peachey and Mallory-Smith 2007). In our study, seeds planted in clay loam soils also had less emergence at shallower depths than when planted in sandy loam soils. The optimal range of seeding depth was narrower and closer to the surface in the clay loam soil for three of the species tested. Specifically, *A. utahensis* and *S. coccinea* emergence in the clay loam soil was significantly reduced at the deepest seeding depth, but emergence was unaffected by seeding depth in the sandy loam soil.

Some studies show that survival of several forb species increases with a slight increase in soil bulk density (Boyd and Van Acker 2003; Reid and Van Acker 2005). This increased bulk density may have improved seedling survival with a 3.2 mm soil covering in the sandy loam soil for *A. utahensis* and *C. acuminata*, and the 6.4 mm seeding depth in both soils for *S. coccinea*. In contrast, lower seedling survival accompanied reduced emergence of *C. acuminata*, *S. coccinea*, and *S. grossulariifolia* at all depths in the clay loam. Benvenuti (2003) and

RECOMMENDED SOWING DEPTHS (MM)

Soil type	*Agoseris glauca*	*Astragalus utahensis*	*Crepis acuminata*	*Sphaeralcea coccinae*	*Sphaeralcea grossulariifolia*
Clay loam	0 to 6.4	3.2 to 6.4	do not sow	6.4	3.2 to 12.7
Sandy loam	0 to 6.4	3.2 to 6.4	3.2	6.4	6.4 to 12.7

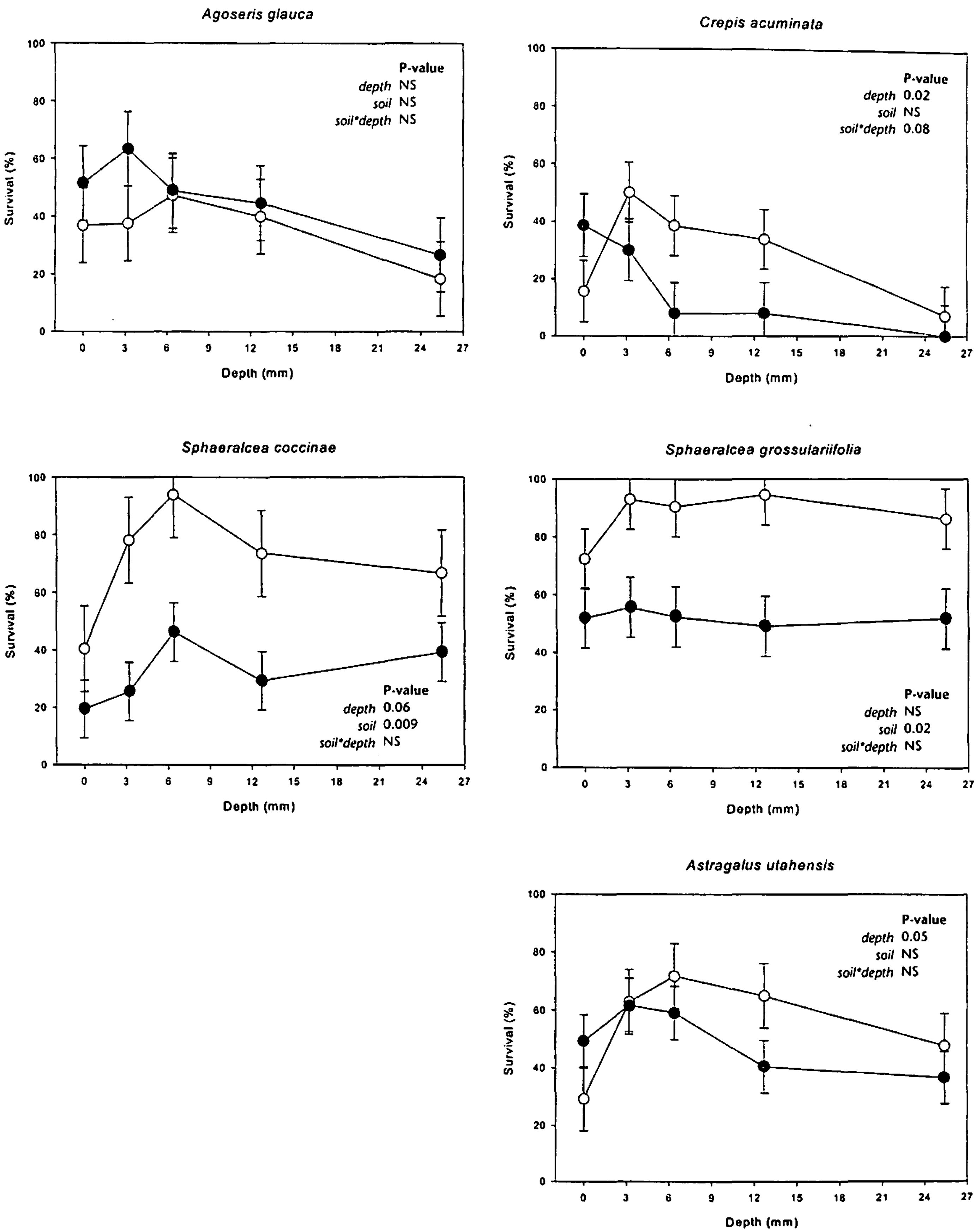

Figure 3. Survival of forbs in clay loam (black circles) and sandy loam (white circles) soils. Significance of depth, soil, and their interaction on forb survival is reported. Significance is defined as $P \leq 0.10$.

Peachey and Mallory-Smith (2007) likewise reported reduced seedling emergence with higher bulk densities soils. These responses suggest optimal seeding depths for survival are more specific to species and soil texture than explained by traditional generalizations such as seed size (Boyd and Van Acker 2003). For example, we observed that the *Sphaeralcea* species were not as negatively affected by deeper seeding depths as was the larger seed of *A. utahensis.*

CONCLUSIONS

Based on our observations of maximum emergence and survival, we recommend that *S. coccinea and S. grossulariifolia* be seeded between 3.2 mm and 12.7 mm deep in the soil. *Sphaeralcea coccinea* is more sensitive to seeding depth and soil texture than is *S. grossulariifolia. Crepis acuminata* is adapted to sandy soils (USDA 2007) and has limited emergence (< 12%) and establishment (< 41%) in clay loam soils; this species is not recommended for sowing in areas with high clay content. In sandy loam soils, *C. acuminata* seeds left uncovered after surface sowing will have high emergence but suffer high mortality even when water is not limiting; therefore, a depth between 3.2 mm and 6.4 mm is recommended. The present study confirms other recommendations for *A. glauca* (Walker and Shaw 2005) indicating this species can be surface sowed when water is not limiting or seeded to a depth of 6.4 mm in dryer soils. Both sowing methods will produce high emergence and survival in either clay or sandy loam soils (Walker and Shaw 2005). Seedling mortality of *A. utahensis* is high when surface seeded, and germination is inhibited at a seeding depth of 25.4 mm. Seeding at depths between 3.2 mm and 6.4 mm is recommended to maximize emergence and survival of this forb. All forbs had significantly less emergence or survival at the 25.4 mm seeding depth. Seeding these forbs at or below this depth is not recommended.

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