Priming Wildflower Seed Mixtures Increases Sod Production Rate[1]

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Abstract

Wildflower sod was established in a greenhouse by sowing primed or non-primed seeds of two seed mixtures at 2× (2.44 g/m^2, 0.5 lb/1000 ft^2) or 10× (12.20 g/m^2, 2.5 lb/1000 ft^2) the supplier's recommended field broadcast rate onto a 2.5 cm (1 in) settled depth of commercial peat-lite (ProMix BX) contained in 28 × 52 × 5 cm (11 × 20.5 × 2 in) flats. One seed mixture (NE, Northeast) contained 54% of the species as annuals, the remainder being biennial and perennial species. The other mixture (NEANN) was a 1:1 (weight) combination of NE with a 100% annual species mixture. Seeds were primed matrically in expanded, fine-grade vermiculite for four days at –0.5 MPa at 15C (59F) in darkness (vermiculite:water:seed, 5:5:1 by wgt). At five weeks after sowing, root rating (an estimate of rooting magnitude), sod stability (an estimate of resistance to sod separation), and shoot dry weights were increased as a result of sowing primed NEANN seeds at 10×. Sod netting with 2.8 cm (1.1 in) openings, whether placed at the bottom or top of the substrate, had no effect on these variables. Sod of a duplicate, concurrent experiment was transplanted in the field at five weeks after sowing. By 12 weeks after sowing, the 10× seeding rate increased shoot dry weight, but the effect of seed priming on shoot dry weight had been lost.

Index words: wildflowers, wildflower sod, matric priming.

Significance to the Nursery Industry

Results of this study have shown that wildflower sod stability (its resistance to breakage) was increased by sowing seed mixtures with a higher annual species content and by sowing at 10× rather than 2× the recommended rates for broadcasting in the field. Matric priming of the seed mixture, a technique accomplished with minimal equipment or expertise, likewise greatly enhanced sod stability. Increased sod stability would lessen the time required for wildflower sod production in the greenhouse or nursery.

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Introduction

Increased use of wildflowers in landscapes in recent years may reflect a desire for an alternative to other groundcovers including turfgrass. Wildflowers provide aesthetic appeal and a habitat and food for wildlife, and are a source of cut flowers. The traditional method of establishing a wildflower planting, by the broadcasting of seeds onto tilled, vegetation-free land, can result in poor stands owing to low percentage seed germination or seedling emergence (10) and excessive competition from weed species establishing at the same time from the seedbed seed bank (2, 15).

Sod has been used to establish turfgrass for many years. Cisar and Snyder (4) in 1992 showed that turfgrass sod could be produced successfully in compost on plastic in the field; the plastic providing a barrier to weed growth from the underlying soil and facilitating the sod harvest. In the first known reports of successful wildflower sod production in 1979 (1) and 1983 (2), cheesecloth was placed both below and on top of three commercial peat-lites. Recent work on wildflower sod has focused on the use of municipal and other solid wastes as the substrate for production on sod on plastic (8, 9, 10). However, Johnson and Whitwell (6) evaluated 29 field-sown wildflower species for sod development based on ratings for appearance, root mat density, and stability following undercutting and storage, application of growth suppressing regulators, and performance after transplanting.

The production of wildflower sod in soilless media under greenhouse or nursery conditions can provide a higher percentage of wildflower seed establishment without competition from weeds. When transplanted under field conditions, the sod reduces competition from soil-borne weed seeds and provides immediate beauty and soil stabilization. If planting must be delayed, the sod can be held for varying periods until planting conditions are favorable. Methods that speed production of high tensile strength wildflower sod can reduce production costs by lessening greenhouse or nursery space costs.

Mitchell and Barton (8) reported that plastic turfgrass netting [1.9 cm (0.75 in) openings] placed under 2.5 cm (1 in) depths of municipal waste compost or peat-lite significantly increased the tensile strength of sod grown in flats. Airhart and Falls (1) noted that fishnet-type netting was less satisfactory than cheesecloth in wildflower sod production, apparently because cheesecloth was 'more flexible and permitted greater root growth'. In subsequent work (2), cheesecloth was placed both below and above the peat-lite for wildflower sod production.

Both seed mixture and seed rate have influenced wildflower sod production. Mitchell and Barton (8) reported that more rapid establishment and growth of plants from an annual wildflower seed mixture than from a mixture containing annual, biennial and perennial wildflower species corresponded with greater sod tensile strength. Mitchell and Barton (8) used 2× while O'Brien and Barker (9, 10) used 4× the supplier's recommended rate for field broadcasting in the production of wildflower sod, with no reasons given for these selected rates. Airhart et al. (2) compared 1× to 20× the supplier's recommended field broadcast rates of 12 wildflower species in the production of wildflower sod. They noted that when sown as single species in peat-lite, wildflower species interacted with seeding rate in affecting sod quality. The best sod (based on sod strength, rooting proliferation, and seedling shoot growth) was achieved with 1× seeding rate for three species, 5× for three species, 10× for four species, and 20× for two species which were tap-rooted.

Seed priming is a technique in which seeds are exposed to a low external water potential induced either osmotically or matrically to permit partial seed hydration and many pregerminative physiological and biochemical processes but to prevent germination (12). Seeds of purple coneflower (*Echinacea purpurea* (L.) Moench) had greater rate, synchrony and percentage of germination following osmotic priming in polyethylene glycol or matric priming in expanded vermiculite than non-primed seeds (13). Pill et al. (13) concluded that moistened vermiculite substituted for polyethylene glycol solution as a priming medium because benefits to seed germination or seedling emergence following priming in either medium were similar. Expanded vermiculite as the priming agent for wildflowers is particularly advantageous for broadcast sowing because seeds would not have to be separated from the vermiculite. Following seed priming in vermiculite, more vermiculite could be added to increase the bulk volume and aid uniformity of seed dispersal. Tallowin et al. (15) reported that seeds of 60 wildflower species commonly found in seed mixtures showed wide variation among species both in germination rate and final germination percentage. Priming decreased the overall heterogeneity by increasing the germination rate in 50 species and increasing the percentage germination in 15 species.

In this study we examined the effect of turf net presence and position, seed mixture, seed rate and seed priming on greenhouse-grown sod quality and on post-transplanting growth in the field.

Materials and Methods

Seed mixture treatments were the Northeast mixture (NE) and a 1:1 (weight) combination of the NE and the All-Annual mixture (NEANN) (The Vermont Wildflower Farm, Charlotte, VT; Table 1). Although the supplier's recommended seed rate for these mixtures is 1.22 g/m^2 (0.25 lb/1000 ft^2), we selected 2.44 g/m^2 (0.5 lb/1000 ft^2) as the lower rate (2×) and 12.2 g/m^2 (2.5 lb/1000 ft^2) as the higher rate (10×). The lower rate was that used by Mitchell and Barton (8), and the 10× rate promoted the greatest sod quality in more wildflower species than any other rate (2).

Sod production occurred in 28 × 52 × 5 cm (11 × 20.5 × 2 in) plastic flats. Black polyethylene plastic was placed in the bottom of each flat. Turf netting (Turfnit, Delmarva Textile, Milford, DE) with 2.9 cm (1.1 in) openings was cut into 28 × 52 cm (11 × 20.5 in) pieces and placed either on the black plastic or on the top of a commercial peat-lite (ProMix BX; Premier Brands, New Rochelle, NY), which filled the flats to a settled depth of 2.5 cm (1 in). Seeds to be matrically primed were mixed at a dry weight ratio of 1:5 seed:expanded vermiculite (No. 5 grade; W.R. Grace, Cambridge, MA). Water at 100% of the vermiculite dry weight then was stirred into the seed-vermiculite mixture to provide an initial matric potential of –0.5 MPa (–5 bars) (7). The seed-vermiculite-water mixture was transferred to a 200 ml (7 oz) plastic drinking cup, and aluminum foil was secured over the cup top. The seeds were allowed to prime for 4 days in darkness at 15C (59F).

On the day of sowing, the non-primed seeds were mixed thoroughly with 30 g (1.1 oz) of dry vermiculite. So that the amount of vermiculite used to assist in seed dispersal was equal for the primed seeds, a lower amount of dry vermiculite was added to the primed seeds and moist vermiculite. For the 2× and 10× seed rates, respectively, vermiculite additions were 28 g (1 oz) and 20.5 g (0.73 oz). The seed-vermiculite mixture was broadcast manually onto the surface of the peat-lite, covered with 1 cm (0.4 in) depth of peat-lite, and watered to beyond saturation. The flats received water by sprinkler irrigation as needed. Treatments in this 2 (seed mixture) × 2 (seed rate) × 2 (non-primed or primed seeds) × 3 (netting presence or position) factorial experiment were arranged in randomized complete blocks with four replications in a glasshouse [90% transmission, 23–27C (73–81F) day, 17–21C (63–70F) night] under natural light (May–June). This experiment was duplicated concurrently; one for sod production evaluation after five weeks, and one for transplanting into field plots.

At five weeks after seed sowing, shoots were cut at 1 cm (0.4 in) above the peat-lite surface and their dry weight de-

Table 1. Wildflower species in the Northeast Mixture and All-Annual Mixture[z].

Northeast Mixture		All-Annual Mixture	
Common name	**Scientific name**	**Common name**	**Scientific name**
Annuals		Baby blue eyes	*Nemophila menziessi* Hook & Arn.
Annual sunflower	*Helianthus annuus* L.	Snapdragon	*Linaria maroccana* Hook.
Baby blue eyes	*Nemophila menziesii* Hook & Arn.	Baby's breath	*Gypsophila elegans* Bieb.
None-so-pretty	*Silene armeria* L.	California poppy	*Eschscholzia californica* Cham.
Plains coreopsis	*Coreopsis tinctoria* Nutt.	Chinese forget-me-not	*Myosotis sylvatica* Hoffm.
California *poppy*	*Eschscholzia californica* Cham.	Bachelor's button	*Centaurea cyanus* L.
Red poppy	*Papaver rhoeas* L.	Farewell-to-spring	*Clarkia elegans* Dougl.
Rose mallow	*Hibiscus trionum* L.	Four o'clock	*Mirabilis jalapa* L.
Scarlet flax	*Linum grandiflorum* Desf.	Globe gilia	*Gilia capitata* Dougl.
Wild larkspur	*Delphinium ajacis* L.	Godetia	*Godetia amoena* Don.
Cosmos	*Cosmos bipinnatus* Cav.	Indian blanket	*Gaillardia pulchella* Foug.
Orange cosmos	*Cosmos sulphureus* Cav.	None-so-pretty	*Silene armeria* L.
Farewell-to-spring	*Clarkia elegans* Dougl.	Plains coreopsis	*Coreopsis tinctoria* Nutt.
Baby's breath	*Gypsophila elegans* Bieb.	Red poppy	*Papaver rhoeas* L.
Bachelor's button	*Centaurea cyanus* L.	Rose Mallow	*Hibiscus trionum* L.
Catchfly	*Silene armeria* L.	Scarlet flax	*Linum grandiflorum* Desf.
Biennials		Orange cosmos	*Cosmos sulphureus* Cav.
Wallfower	*Cheiranthus allionii* Hort.	Wild annual lupine	*Lupinus texensis* Hook.
Dame's rocket	*Hesperis natronalis* L.	Wild calendula	*Calendula officinalis* L.
Black-eyed susan	*Rudbeckia hirta* L.	Cosmos	*Cosmos bipinnatus* Cav.
Wild sweet william	*Dianthus barbatus* L.	Rocket larkspur	*Delphinium ajacis* L.
Perennials		Annual sunflower	*Helianthus annuus* L.
Birdsfoot trefoil	*Lotus corniculatus* L.		
Ox-eye daisy	*Chrysanthemum leucanthemum* L.		
Mexican hat	*Ratibida columnaris* (Sims) D. Don.		
Lanceleaf coreopsis	*Coreopsis lanceolata* L.		
Gloriosa daisy	*Rudbeckia hirta* Nutt.		
Perennial gaillardia	*Gaillardia aristata* Pursh.		
Perennial lupine	*Lupinus perennis* L.		
Purple coneflower	*Echinacea purpurea* Moench		
Shasta daisy	*Chrysanthemum maximum* Ramond.		

[z]Percentage composition of each species was not reported by The Vermont Wildflower Farm (Charlotte, VT).

termined (65C, 149F). Sod pieces then were turned over so that a qualitative rating of root magnitude could be assessed according to Airhart et al. (2) as 1 = no matting, 2 = slight matting, 3 = full coverage but less dense growth than 4, and 4 = full and solid growth. Next, the sod pieces were grasped with two hands at an end and held vertically to assess sod stability according to Airhart et al. (2) as 1 = loss of roots or substrate or damage to plants, 2 = stretching but no damage to plants, 3 = minimal separation, and 4 = no separation of plants or roots. Data for the three estimates of sod quality were subjected to analysis of variance.

The duplicated sod were hardened by restricting irrigation to cause slight wilting. After 3 days, the sod was transplanted into Matapeake silt loam (fine-silty, mixed mesic, Typic Hapladult) at the University of Delaware. Plots, previously in fine fescues, had been treated with glyphosate (Roundup), tilled to 10 cm (4 in) depth, and raked smooth. Soil test results from a composite sample [2 cm (0.8 in) diameter core to a depth of 15 cm (6 in) from each block] were: 1.0% (weight/weight) organic matter (by ignition), pH 6.4 and electrical conductivity 0.42 dS/m (mmho/cm; both from a saturated extract), total N (0.4% weight/weight) and ions (extracted with Mehlich 1, 0.05N HCl and 0.025N H_2SO_4) in mg/kg of P 56, K 96, Ca 592, Mg 87, Zn 1.5, and Cu 0.4. Wildflower sod pieces (28 × 52 cm, 11 × 20.5 in) were placed on the soil and gently pushed into the loose surface soil with 1 m (39 in) in all directions between them. Plots were arranged in randomized complete blocks with 4 replications. Plots were thoroughly irrigated on the day of transplanting and thereafter received at least 2.5 cm (1 in) of water per week from rain or sprinkler irrigation. Weeds between the sod pieces were removed manually.

At 12 weeks after transplanting, shoots from each sod piece were cut at about 1 cm (0.4 in) above the soil surface, separated into wildflower and weeds, and dry weights (65C, 149F) determined. These data were subjected to analysis of variance.

Results and Discussion

Sod netting, either on the bottom or top, had no effect on sod quality variables (data not shown). These results contradict those of Mitchell and Barton (8) who reported that turf netting in wildflower sod sown at 2× the supplier's recommended field broadcasting rate increased sod tensile strength at six to eight weeks after sowing, thereby reducing sod production time. Airhart and Falls (1) reported that cheesecloth was superior to netting with large openings in wildflower sod production. We may have achieved greater sod stability had we used cheesecloth both above and below the sod substrate as reported by Airhart et al. (2).

Root rating and sod stability at five weeks after sowing were affected by the interaction of seed priming, seed mixture and seed sowing rate (Table 2). Root rating, a visual estimate of root magnitude at the bottom of the sod, was increased both by seed priming and the higher seed rate. Root rating was greatest for primed NEANN seeds sown at 10×, and was lowest for non-primed NE seeds sown at 2×. Sod

Table 2. Sod root rating and stability at five weeks after seed sowing as influenced by seed matric priming, seed mixture and seed sowing rate.

Seed treatment	Seed mixture	Seed rate[z]	Root rating[y]	Sod stability[x]
Non-primed	Northeast	2×	2.1	2.4
		10×	2.8	2.8
	Northeast + Annual	2×	2.5	2.4
		10×	3.2	3.1
Primed	Northeast	2×	2.8	2.8
		10×	3.3	3.2
	Northeast + Annual	2×	3.0	3.8
		10×	3.7	3.8
	$LSD_{0.05}$		0.3	0.3
Significances[w]				
Seed treatment (ST)			***	***
Seed mixture (SM)			**	***
ST × SM			NS	***
Seed rate (SR)			**	NS
ST × SR			**	NS
SM × SR			**	NS
ST × SM × SR			***	***

[z]2 or 10 times the supplier's recommended rate for broadcasting in the field.

[y]Root rating from 1 = no matting, to 4 = full and solid root growth at the bottom of the sod.

[x]Sod stability from 1 = loss of roots or substrate or damage to plants, to 4 = no separation of plants or roots.

[w]NS, **, ***: Not significant, or significant at $P \leq 0.01, 0.001$, respectively.

stability, an estimate of sod tensile strength, was increased by seed priming and by sowing seeds at 10×, except for primed NEANN seeds which had identical and high sod stability values at 2× and 10×. The increase in sod stability as a result of priming was greater for NEANN than for NE seeds, indicating a greater priming benefit to seeds of annual species. The greatest sod stability resulted from primed NEANN seeds sown at 2× or 10×, and the lowest sod stability resulted from sowing non-primed NE or NEANN seeds at 2×. Mitchell and Barton (8), in agreement with our results, reported that an annual seed mixture resulted in greater sod tensile strength than a mixture containing seeds of annual, biennial and perennial species. The general increase in root rating and sod stability as a result of the higher seeding rate (Table 2) was reported for nine of the 12 species used in wildflower sod by Airhart et al. (2). The greater seed cost for the 10× than the 2× sowing rate [about \$0.48/ft^2 (\$5.16/m^2)] may not be justified by the decreased production time (an estimated 7 to 10 days) associated with the higher seeding rate. Root rating and sod stability values generally paralleled each other across treatments indicating that the visible root magnitude at the bottom of sod was related positively to sod stability. When the roots reached the plastic, they grew horizontally along the plastic assisting in binding the sod. From a practical standpoint, sod stability has greater importance than root rating since a high sod stability value would reflect a shorter time to produce sod that could be handled with minimal damage.

Shoot dry weights at five weeks after sowing were increased (as main effects) by priming the seeds, sowing NEANN rather than NE, and sowing at 10× rather than 2× seed rate (Table 3). By 12 weeks after transplanting the sod to the field, shoot dry weights were greater (as main effects) in sod established from NE than NEANN, and by sowing the seed at 10× rather than 2× (Table 3). Shoot dry weights in response to seed mixture reversed between five weeks after sowing and 12 weeks after transplanting, such that NE was 88% that of NEANN at five weeks after sowing and NE was 126% that of NEANN by 12 weeks after transplanting. This reversal may be explained by more rapid growth of a larger proportion of annual species in NEANN by five weeks, which by 12 weeks after transplanting may have undergone some senescence. The lower content of annuals in the NE mix (Table 1) may have resulted in less competition for the biennials and perennials, which had considerable growth by this time of the season. It would be interesting to note the percentage of seedling emergence and subsequent seedling survival in response to the seed mixture composition and seedling rate of the wildflower sod. Weed shoot dry weight was unaffected by treatments (data not shown), and comprised only 5.2% of plot shoot dry weight indicating that the densely vegetated sod provided a barrier against both airborne weeds and weeds attempting to grow through the sod from the underlying soil. Plots of all treatments gave a full and floriferous cover at time of harvest.

The positive effect of seed priming on sod quality variables was maintained for at least five weeks after seed sowing (Tables 2 and 3). Priming may be expected to give greater benefit in more stressful seedbed environments than occurred in the present study. For instance, priming improved emergence of purple coneflower to a greater extent in a cool regime than in a warm regime (13). Priming increased the rate, synchrony and percentage germination and emergence of impatiens (*Impatiens wallerana* Hook f.) at low temperatures and reduced water availability (5). Increased sod quality as a result of seed priming probably resulted from earlier germination and seedling emergence, and not from increased rela-

Table 3. Shoot dry weight at five weeks after seed sowing and at twelve weeks after transplanting into the field as influenced by seed matric priming, seed mixture and seed sowing rate.

Treatment main effects	Shoot dry weight (g m^{-1}): 5 weeks sowing	Shoot dry weight (g m^{-1}): 12 weeks after transplanting[z]
Seed treatment		
Non-primed	17.6	118.9
Primed	19.8	123.4
Significance[y]	*	NS
Seed mixture		
Northeast	17.4	135.1
Northeast + Annual	19.8	107.6
Significance[y]	**	***
Seed rate[x]		
2×	16.7	111.3
10×	20.6	131.5
Significance[y]	***	***

[z]17 weeks after seed sowing.

[y]NS, *, **, ***: not significant, or significant at $P \leq 0.05, 0.01, 0.001$, respectively. All treatment interactions were not significant.

[x]2× or 10× the supplier's recommended rate for broadcasting in the field.

tive growth rate as shown in leek (*Allium porrum* L., 3) and Kentucky bluegrass (*Poa pratensis* L., 14).

Matric priming in moistened expanded, fine-grade vermiculite was an effective priming agent for snap bean (*Phaseolus vulgaris* L., 7). Pill et al. (13) reported that vermiculite can substitute for polyethylene glycol solution as a priming medium for purple coneflower seeds since benefits to seed germination or seedling emergence following priming in these media were similar. Although the priming conditions used in the present study [–0.5 MPa (–5 bars), 4 days, 15C (59F)] were beneficial, altering these conditions may provide further benefit. Our preliminary studies showed that matric priming the wildflower species at –0.5 MPa (–5 bars) at 15C (59F) for 7 days rather than 4 days resulted in germination of several species during priming. Such germination may be avoided by decreasing either the priming temperature or the water potential. For instance, Tallowin et al. (15) osmotically primed seeds of wildflower species at 15C (59F) for 14 days at –1.0 or –1.5 MPa (–10 or –15 bars). Pill et al. (13) showed that priming purple coneflower seeds for 10 days at –0.4 MPa and 15C (59F) resulted in higher germination rate and percentage than shorter (5 day) exposure or lower [–1.5 MPa (–15 bars)] water potential. Brocklehurst et al. (3) noted that the response to a given priming treatment can vary between seed lots of the same cultivar. For wildflower mixtures, the optimal treatment selected for the mixture may not represent the optimal treatment for individual species.

Although the initial matric potentials of the water-vermiculite mixture in our study was nominally –0.5 MPa (–5 bars) as established by a moisture characteristic curve (6), actual matric potentials undoubtedly decreased during priming owing to water imbibition by the seeds and to a small amount of evaporative loss. The high vermiculite:seed weight ratio (5:1) used and vermiculite's high water-holding capacity would ensure a minimal decrease in vermiculite matric potential during seed priming. Expanded vermiculite as the priming agent for wildflowers is particularly advantageous for broadcast sowing because seeds would not have to be separated from the vermiculite. In the present study, we added dry vermiculite to the moist vermiculite in which seeds were primed to increase the bulk volume and aid in uniformity of seed dispersal.

The results of this study have shown that sowing wildflower seeds with a higher annual species content at 10× rather than 2× the supplier's recommended rates for broadcasting in the field contributed to increased sod stablility and hence more rapid sod production. Matric priming of the seed mixture for 4 days in expanded, fine-grade vermiculite (vermiculite:water:seed, 5:5:1 by weight) greatly enhanced sod stability. The sod netting used in this study had no effect on sod stability.

Literature Cited

1. Airhart, D.L. and K.M. Falls. 1979. Wildflower sods for roadsides. HortScience 14:445 (Abstr.)

2. Airhart, D.L., K.M. Falls, and T. Hosmer. 1983. Developing wildflower sods. HortScience 18:89–91.

3. Brocklehurst, P.A., J. Dearman, and R.L.K. Drew. 1984. Effects of osmotic priming on seed germination and seedling growth in leek. Scientia Hortic. 24:201–210.

4. Cisar, J.L. and G.H. Snyder. 1992. Sod production on a solid-waste compost over plastic. HortScience 27:219–222.

5. Frett, J.J. and W.G. Pill. 1989. Germination characteristics of osmotically primed and stored *Impatiens* seeds. Scientia Hortic. 40:171–179.

6. Johnson, A.M. and T. Whitwell. 1997. Selecting species to develop a field-grown wildflower sod. HortTechnol. 7:411–414.

7. Khan, A.A., J.D. Maguire, G.S. Abawi, and S. Ilyas. 1992. Matriconditioning of vegetable seeds to improve stand establishment in early field plantings. J. Amer. Soc. Hort. Sci. 117:41–47.

8. Mitchell, W.H. and S.S. Barton. 1994. Using composts to grow wildflower sod. BioCycle 35:62–63.

9. O'Brien, T. and A.V. Barker. 1995. Evaluation of fresh and year-old solid waste composts for production of wildflower and grass sods on plastic. Compost Sci. and Utilization 3:69–77.

10. O'Brien, T. and A.V. Barker. 1997. Evaluating compost to produce wildflower sods on plastic. J. Amer. Soc. Hort. Sci. 122:445–451.

11. Phillips, H.R. 1985. Growing and propagating wild flowers. Univ. of North Carolina Press, Chapel Hill.

12. Pill, W.G. 1994. Low water potential and presowing germination treatments to improve seed quality. *In*: A.S. Basra (Editor), Seed Quality: Basic Mechanisms and Agricultural Implications. Haworth Press, Binghampton, NY.

13. Pill, W.G., C.K. Crossan, J.J. Frett, and W.G. Smith. 1994. Matric and osmotic priming of *Echinacea purpurea* (L.) Moench seeds. Scientia Hortic. 59:37–44.

14. Pill, W.G. and T.K. Korengel. 1997. Seed priming advances the germination of Kentucky bluegrass (*Poa pratensis* L.). J. Turfgrass Mgt. 2:27–43.

15. Tallowin, J.R.B., A.J. Rook, and S.K.E. Brookman. 1994. The effects of osmotic pre-sowing treatment on laboratory germination in a range of wild flower species. Ann. Appl. Biol. 124:363–370.