Plug Characteristics and Post-transplanting Container Size affect Growth of Little Bluestem and Lanceleaf Coreopsis[1]

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Abstract

Two studies were conducted to determine the effects of several factors on growth of containerized lanceleaf coreopsis (*Coreopsis lanceolata* L.) and little bluestem (*Schizachyrium scoparium* (Michx.) Nash.). In the first study, seeds were sown in 22 cm^3 (1.3 in^3) plug cells and then transplanted, with or without root disturbance (manually teasing roots from the root ball and directing them radially from the plant axis) into 3.78 liter (1 gal) containers at 35 days (young) or 49 days (old) after planting. By 35 days after transplanting, old transplants of both species had greater shoot dry weight than young ones even though the latter had greater shoot relative growth rate and shoot net assimilation rate between 0 and 35 days after transplanting (DAT). By 107 DAT, old *Schizachyrium* transplants had more shoot dry weight than young ones, but *Coreopsis* shoot dry weight was unaffected by transplant age. Root disturbance, irrespective of transplant age and species, decreased shoot dry weight at 35 DAT and decreased shoot relative growth rate between 0 and 35, but had no effect on these variables by 107 DAT. In the second study, transplants were raised in small (22 cm^3, 1.4 in^3) or large (84 cm^3, 5.1 in^3) cells, then transplanted at 62 or 76 days after planting, respectively, (to assure similar shoot size to plug cell volume ratio and to avoid root restriction) into small (15 cm, 6 in) or large (20 cm, 8 in) diameter standard pots. Shoot dry weights of both species were greater from large plug cell transplants by 35 DAT, but only of *Coreopsis* by 107 DAT. Large post-transplanting containers further contributed to the growth advantage of transplanting plants from large plug cells, responses that could be attributed to greater supplies of water nutrients in larger plug cells and post-transplanting containers.

Index words: *Schizachyrium scoparium* (Michx.) Nash., little bluestem, *Coreopsis lanceolata* L., lanceleaf coreopsis, shoot relative growth rate, shoot net assimilation rate, plug production, plug cell volume, plug transplant age, root ball disturbance.

Species used in this study: *Schizachyrium scoparium, Coreopsis lanceolata.*

Significance to the Nursery Industry

Several practices in the production of containerized lanceleaf coreopsis and little bluestem grass were examined with the purpose of increasing shoot size and thereby reducing production time. The first study established that transplanting older plug cell plants (49 days after sowing) rather than younger ones (35 days after sowing), and avoiding root ball disturbance (manually teasing roots from the root ball and directing them radially from the plant axis) resulted in the greatest shoot mass by 35 or 107 days after transplanting into 3.78 liter (1 gal) containers. The second study established that using larger plug cells (84 vs 22 cm^3, 5.1 vs 1.4 in^3) followed by larger post-transplanting containers (20 vs 15 cm, 8 vs 6 in diameter standard pots) resulted in the greatest shoot mass by 35 or 107 days after transplanting.

Introduction

Plug transplants, plants grown in small-volume cells, are used in the production of ornamental and vegetable crops, and the trend is towards more cells per plug tray (smaller cells) which increases the number of plants produced per unit area of greenhouse or nursery space (18), thereby reducing production cost per plant (6). As plug cell size decreases, smaller root volumes increase the potential for root (growth) restriction that can lead to a 'pot-bound' ('root-bound') condition. Thus, transplant age and plug cell size are related factors, since transplants would reach root restriction sooner in their ontogeny as cell size decreases. NeSmith and Duval (13) noted that reduced rooting volume and root restriction can affect root and shoot growth, biomass accumulation and partitioning, photosynthesis, leaf chlorophyll concentration, plant water relations, nutrient uptake, respiration, flowering and yield, although data are conflicting with different responses reported between species and even between cultivars within a species. In general, plant leaf area, and shoot and root biomass decrease as container size decreases (4). For instance, decreasing cell size (increasing root restriction) decreased both leaf number and size in *Euonymus kiautschovica* Loes. (5) and in *Salvia splendens* F. Sellow ex Roem & Schult. (17), decreased shoot height and biomass in *Tagetes erecta* L. (11), decreased shoot biomass in *Ilex cornuta* Lindl. & Paxt., *Euonymus japonica* Thunb. and *Rhododendron* x *sp*.('Hershey Red' azalea) (9), and reduced branching and lateral shoot growth in *S. splendens* (17). Root restriction lowered post-transplanting net assimilation rate in *S. splendens* (17) and lowered relative growth rate in *Euonymus kiautschovica* (5). Plants can exhibit a growth check ('transplanting shock') after transplanting. For instance, Knight et al. (10) found that delayed post-transplanting shoot elongation of two *Ilex* species (*I. aquifolium* L. x *I. cornuta* Lindl. & Paxt. and *I. cornuta* Lindl. & Paxt.) was proportional to the degree of root restriction caused by small propagation containers or delayed transplanting. McKee (12) noted that deleterious effects of root restriction on growth following transplanting were more pronounced when they occurred later in plant ontogeny since older plants had less time for readjustment of their vegetative development before initiation of reproductive growth or maturation of the vegetative phase.

Plants grown in containers for long periods frequently develop roots that grow in circles that follow the container

[1]Received for publication July 17, 2006; in revised form January 30, 2007.

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contour. Following transplanting, these roots may continue to follow the contour of the now-removed container rather than radiate from the collar in a shallow, horizontal plane. With such pot/root-bound plants, mechanical disturbance of roots is a common practice with the intent of stimulating new root growth radial to the root ball (7). Scoring (2.5 cm (1 in)-deep slices around the root ball at 90° intervals and an X-shaped slice across the bottom) or teasing (roots manually pulled out of the shape in the container in a direction perpendicular to the stem) are two such mechanical disturbance practices. Responses to these practices have been variable. For instance, Arnold (1) found that mechanical disturbance that severed roots of pot-bound *Quercus shumardii* Buckl. decreased field performance and increased post-transplant water stress compared to responses from non-disturbed root ball. Gillman et al. (8) noted that mechanically disturbing pot-bound root balls of *Salix alba* L. and *Tilia cordata* Mill. failed to result in more roots growing beyond the pot-bound mass two years after transplanting. An initial response to root ball disturbance of woody species is increased root dry weight accompanied by decreased shoot growth (3, 15). To our knowledge, post-transplanting responses to root disturbance of plug transplants have not been examined. Tomato plants grown in seed trays with an equal volume of growth medium per plant as plants grown in single cells, however, were smaller at transplanting and final harvest, a response attributed to root disturbance at transplanting (12).

Transplanting liners into larger containers generally results in increased canopy growth of fruit and ornamental species (2). For instance, Keever et al. (9) noted that although post-transplanting shoot growth of *Ilex cornuta*, *Euonymus japonica* and *Rhododendron* x sp. liners increased as pot width increased, only in the *Rhododendron* x sp., with a more shallow and fibrous root system, did increasing pot depth fail to increase shoot growth. The authors suggested that while increased shoot growth could be attributed to increased growth medium volume with increasing container size, shoot growth could be maximized by growing shallow-rooted species in shallow, broad containers, and deep-rooted species in pots deeper than standard nursery pots. There are differences in opinion as to whether plugs or liners should be transplanted directly into market-size containers or transplanted into intermediate-sized containers before transplanting into the market container (upcanning). Upcanning is more labor-intensive and requires less space; however, Beeson (2) reports that nursery operators using upcanning assert that canopy growth is accelerated compared to direct planting into market sized containers, thus reducing production time and overhead cost. Upcanning 'Red Tip' photinia (*Photinia* x *fraseri*) rooted cuttings from 0.9 to 2.9 to 10.2 liters (0.25 to 0.75 to 2.7 gal) containers maintained or increased plant growth rate, whereas growth rates of plants kept in the same container generally declined during the second season (2). Upcanning seemed to take advantage of more rapid growth in smaller containers while avoiding growth checks due to root restriction. Increased efficiency of water or nutrient absorption resulting from increased fine diameter root mass at the periphery of the *Photinia* root ball with each upcanning was speculated as a likely cause of greater growth with upcanning. Slash pine (*Pinus elliottii* Engelm.), however, failed to benefit from upcanning with maximal growth occurring in the largest initial container, possibly because this species has a coarser root system (2).

The purpose of this research was to examine the effects of several factors that may affect post-transplant growth of *Coreopsis lanceolata* and *Schizachyrium scoparium*. The first study examined plug transplant age and root ball disturbance at time of transplanting, and the second study examined plug cell volume and post-transplanting container volume.

Materials and Methods

Transplant age and root ball disturbance. Seeds of *Coreopsis lanceolata* L. and *Schizachyrium scoparium* (Michx.) Nash. were sown in128 square plug flats (128, 22 cm^3 (1.34 in^3)) cells per 27.5 × 55 cm (10.8 × 21.7 in) flat (TLC Polyform, Inc., Plymouth, MN) containing peat-lite (ProMix BX, Premier Horticulture Inc., Redhill, PA) at 14 days apart. Seeded flats were kept under mist until seedling emergence. Seedlings were thinned to one per cell after developing true leaves and placed in a glasshouse set at 23/19C (73/66F) day/night with natural light during May–July. The plug trays received 100 mg N/liter (ppm N) weekly from 20N–4.3P–16.6K (20N–10P$_2$0$_5$–20K$_2$O; Peters Professional General Purpose (Scotts-Sierra Horticultural Products Co., Marysville, OH).

Plugs were transplanted into ProMix BX contained in 3.8 liter (1 gal) nursery containers (Poly-Tainer-Can, Nursery Supplies, Inc., Orange, CA) at 35 (young plugs) or 49 days (old plugs) after planting. Roots of one-half of the plugs of each age group were disturbed by manually teasing them from the root ball and directing them radially from the plant axis, while root balls of the other half were transplanted without root disturbance. At time of transplanting, five plants from each age group were cut at the growth medium surface to determine shoot dry weight and leaf area. Leaf area was determined using a leaf area meter (Model LI-3000A, LiCor, Lincoln, NE). All parts of the shoot then were placed in an oven (65C, 149F) for two weeks for dry weight determination. Plants received 200 mg N/liter (ppm N) weekly from 20N–4.3P–16.6K. The 2 (plug age) × 2 (root disturbance) factorial was arranged in a randomized complete block design with 4 replications of 10 plants per treatment combination. At 35 and 107 days after transplanting (DAT), shoots of five plants randomly selected from each replication were cut at the growth medium surface and their leaf areas and dry weights determined as described above.

Leaf area (LA) and shoot dry weight (SDW) were used to calculate shoot net assimilation rate (SNAR) and shoot relative growth rate (SRGR) using the following equations: $SNAR = (SDW_2 - SDW_1) (\log_e LA_2 - \log_e LA_1) / (LA_2 - LA_1) (t_2 - t_1)$, and $SRGR = (\log_e SDW_2 - \log_e SDW_1) / (t_2 - t_1)$, where t = time, and 1 and 2 represent the starting and ending times, respectively. These variables were calculated during the periods of 0 to 35 DAT and 35 to 107 DAT. All data were subjected to analysis of variance.

Plug cell volume and post-transplanting container volume. Two or three seeds of *Coreopsis* or *Schizachyrium* were sown in peat lite (Pro-Mix BX) in 4.7 × 4.7 × 5.6 cm deep (84 cm^3) plug cells (large; 1.9 × 1.9 × 2.2 in deep; 5.1 in^3; T.O. Plastics Inc., Bloomington, MN) and two weeks later in 2.7 × 2.7 × 4.5 cm deep (22 cm^3) plug cells (small; 1.1 × 1.1 × 1.8 in deep; 1.4 in^3). The different size plugs were sown at different times to assure a similar plant size to plug cell volume ratio and to reduce possible root restriction in the small plugs. Plug trays were kept under mist until seedlings emerged, thinned to one seedling per cell, then they were moved to a greenhouse (identical conditions as above) where they received daily irrigation and weekly 100 mg N/liter (ppm N) from 20N–4.3K–16.6K.

Plants from small and large plug cells were transplanted into ProMix BX in 15 cm (small, 6 in) or 20 cm (large, 8 in) diameter standard plastic pots (ITML Horticultural Products, Inc., Brantford, ON, Canada) at 62 and 76 DAP, respectively. Plants received daily irrigation and weekly 200 mg N/liter (ppm N) from 20N–4.3P–16.6K. The 2 (plug cell volume) × 2 (post-transplanting container volume) factorial was arranged in a randomized complete block design with 4 replications of 10 plants per treatment combination. Leaf areas and shoot dry weights of five plants of small or large plugs were determined on the day of transplanting. At 35 and 107 DAT, shoots of 5 plants within each replication were cut at the growth medium surface and their leaf areas and dry weights determined as described above. SNAR and SRGR were calculated for the periods 0 to 35 DAT and 35 to 107 DAT, and all data were subjected to analysis of variance.

Results and Discussion

Transplant age and root ball disturbance. For *Coreopsis*, no variables were affected by interactions of transplant age and root ball disturbance (Table 1). By time of transplanting, older seedlings (49 vs 35 DAP) had 3-fold the leaf area and 4-fold the shoot dry weight, and exhibited more root restriction. This response can be attributed to the relative stages of the two transplant ages in the sigmoidal growth curve; younger transplants being more in the slow lag phase while older ones had entered the rapid logarithmic phase. By 35 DAT into 3.8 liter (1 gal) containers, however, transplant age had no effect on leaf area, but the older transplants had 21% greater shoot dry weight. By 107 DAT, neither leaf area nor shoot dry weight was affected by transplant age. Between both 0 and 35 DAT or 35 and 107 DAT, younger transplants had greater SNAR (greater photosynthetic efficiency per unit leaf area) and SRGR (efficiency of existing dry matter to produce new dry matter). Greater root restriction as occurred in the older transplants reduced the NAR of *Salvia splendens* (17) and reduced the RGR of *Euonymus kiautschovica* (5). Younger coreopsis transplants thus exhibited greater growth rates than older ones following transplanting, especially during the first 35 days, because they were further into the logarithmic growth phase and possibly because they were less root-bound. It is possible that older, more root-bound transplants underwent a transplant shock check in growth. Knight et al. (10) noted that delayed post-transplanting shoot elongation in two *Ilex* species was proportional to the extent of root restriction.

At time of transplanting, we observed that *Coreopsis* transplants of both ages were root-bound, but the condition was more severe in older plugs. Irrespective of transplant age, root disturbance at time of transplanting decreased *Coreopsis* shoot dry weight by 10.7% at 35 DAT, although leaf area was unaffected (Table 1). Others have reported that an early response to root ball disturbance is decreased shoot growth as assimilates are directed to the root system, resulting in greater root growth (1, 3, 15); however, we did not measure root growth. Root disturbance resulted in reduced SNAR and SRGR between 0 and 35 DAT, perhaps reflecting a response to the root injury. Between 35 and 107, SNAR and SRGR were unaffected by root disturbance, reflecting recovery from injury due to root disturbance. Such a recovery may have contributed to shoot dry weight being unaffected by root disturbance by 107 DAT, although leaf area was decreased slightly. Thus, disturbing roots to rectify the root-bound condition was unnecessary for *Coreopsis*.

Schizachyrium responded similarly to *Coreopsis* to both transplant age and root ball disturbance at transplanting, with neither factor interacting to affect shoot dry weight or leaf area at 35 or 107 DAT, and SNAR or SRGR at 0 to 35 DAT or 35 to 107 DAT (Table 2). By 35 DAT, older transplants had greater shoot dry weight and leaf area. By 107 DAT, leaf area was unaffected by transplant age, and shoot dry weight was 20% greater in the transplants. The younger transplants exhibited higher SNAR and SRGR between 0 and 35 DAT, and higher SRGR between 35 and 107 DAT. Thus, differences in post-transplant growth as a result of plug age at transplanting lessened with increasing time after transplanting.

Root ball disturbance at time of transplanting reduced leaf area and shoot dry weight of *Schizachyrium* at 35 DAT by 23 and 25%, respectively, responses associated with lower SRGR (Table 2). These decreases could be attributed to preferential directing of assimilates to roots in response to root disturbance, a response noted elsewhere (1, 3, 15). By 107 DAT,

Table 1. Leaf area (LA) and shoot dry weight (SDW) at 0, 35, and 107 days after transplanting (DAT), and shoot net assimilation rate (SNAR) and shoot relative growth rate (SRGR) between 0 and 35 DAT or 35 and 107 DAT of *Coreopsis lanceo*lata as influenced by transplant age (days after transplanting, DAP) and root ball disturbance at time of transplanting.

	0 DAT		35 DAT				107 DAT			
Treatments	LA (cm^2)	SDW (g)	LA (cm^2)	SDW (g)	SNAR ($g/cm^2/d)10^5$	SRGR $(mg/g/d)10^4$	LA (cm^2)	SDW (g)	SNAR ($g/cm^2/d)10^5$	SRGR $(mg/g/d)10^4$
Transplant age										
Young (35 DAP)	12.2	0.10	1151	7.35	88	1208	3554	55.44	82	282
Old (49 DAP)	37.1	0.43	1260	8.93	75	867	3748	57.15	64	258
Root ball disturbance										
No	NA[z]	NA	1225	8.60	85	1055	3798	57.33	72	264
Yes	NA	NA	1186	7.68	77	1021	3504	55.26	75	275
Significances[y]										
Transplant age (TA)	***	***	NS	***	**	***	NS	NS	***	***
Root ball disturbance (RD)	NA	NA	NS	**	*	**	*	NS	NS	NS
TA × RD	NA	NA	NS	NS	NS	NS	NS	NS	NS	NS

[z]NA: Not applicable.

[y]NS, NA, *, **, ***: Non-significant, not applicable, or significant at $P \le 0.05$, 0.01, 0.001, respectively.

Table 2. **Leaf area (LA) and shoot dry weight (SDW) at 0, 35, and 107 days after transplanting (DAT), and shoot net assimilation rate (SNAR) and shoot relative growth rate (SRGR) between 0 and 35 DAT or 35 and 107 DAT of *Schizachyrium scoparium* as influenced by transplant age (days after transplanting, DAP) and root ball disturbance at time of transplanting.**

	0 DAT		35 DAT				107 DAT			
Treatments	LA (cm^2)	SDW (g)	LA (cm^2)	SDW (g)	SNAR ($g/cm^2/d$)10^5	SRGR (mg/g/d)10^4	LA (cm^2)	SDW (g)	SNAR ($g/cm^2/d$)10^5	SRGR (mg/g/d)10^4
Transplant age										
Young (35 DAP)	16.9	0.05	361	1.56	41	1087	1652	30.98	79	420
Old (49 DAP)	62.4	0.23	560	2.37	30	653	1888	37.26	86	386
Root ball disturbance										
No	NA[z]	NA	520	2.23	37	917	1837	35.68	84	391
Yes	NA	NA	403	1.68	32	823	1703	32.55	81	415
Significances[y]										
Transplant age (TA)	***	***	***	***	**	***	NS	*	NS	*
Root ball disturbance (RD)	NA	NA	**	**	NS	**	NS	NS	NS	NS
TA × RD	NA	NA	NS	NS	NS	NS	NS	NS	NS	NS

[z]NA: Not applicable.

[y]NS, NA, *, **, ***: Non-significant, not applicable, or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

injury resulting from root ball disturbance had been overcome since plant growth was unaffected. We know of no reports on growth responses to root disturbance of plugs, which is surprising given the importance of plugs in the greenhouse and nursery industries.

We conclude that both *Coreopsis lanceolata* and *Schizachyrium scoparium* responded similarly to transplant age and root disturbance treatments. Older transplants were larger at transplanting, but younger ones had greater shoot growth rates resulting in a lessening of shoot mass differences between young and old transplants with increasing time after transplanting. Root disturbance of transplants, irrespective of transplant age (and degree of root restriction), was an unnecessary and injurious practice. Transplanting older plugs and avoiding root disturbance at transplanting resulted in the greatest shoot mass.

Plug cell volume and post-transplanting container volume. Growing *Coreopsis* in larger plug cells (84 vs 22 cm^3; 5.1 vs 1.4 in^3) resulted in 7.4- and 11.7-fold increases in leaf area and shoot dry weight, respectively, at time of transplanting (Table 3). Some of this growth differential can be attributed to the longer growth period in larger plug cells which were planted two weeks earlier in an attempt to avoid root restriction at time of transplanting (62 and 76 DAP for small and large plug cells, respectively). In agreement with these results, larger cells resulted in greater shoot biomass than smaller cells in *Tagetes erecta* (11) and in *Ilex cornuta*, *Euonymus japonica*, and *Rhododendron* x sp. (9). Vegetable transplants, likewise, generally have greater leaf area, and shoot biomass in larger plugs (4). Lower supply of water and nutrients in the smaller growth medium volume of smaller cells may have contributed to smaller transplants, as noted for *Lactuca sativa* transplants (14). Irrigation and fertilization regimes would greatly affect growth differentials due to plug cell size. Since both plug cell sizes were irrigated once daily, growth media in the smaller container with about one-fourth the volume, may have dried to a greater extent between irrigations. Larger plug cells were about 1 cm (0.4 in) taller, and only in the top 1 cm of growth medium would water be less available since matric potential decreases by only –0.1 kPa with every 1 cm (0.4 in) in growth medium height (16).

Table 3. **Leaf area (LA) and shoot dry weight (SDW) at 0, 35, and 107 days after transplanting (DAT), and shoot net assimilation rate (SNAR) and shoot relative growth rate (SRGR) between 0 and 35 DAT or 35 and 107 DAT of *Coreopsis lanceolata* as influenced by plug cell volume and post-transplant container diameter.**

	0 DAT		35 DAT				107 DAT			
Treatments	LA (cm^2)	SDW (g)	LA (cm^2)	SDW (g)	SNAR ($g/cm^2/d$)10^5	SRGR (mg/g/d)10^4	LA (cm^2)	SDW (g)	SNAR ($g/cm^2/d$)10^5	SRGR (mg/g/d)10^4
Plug cell volume										
Small (22 cm^3, 1.4 in^3)	23.7	0.18	1165	8.59	81	1375	1976	41.54	81	233
Large (84 cm^3, 5.1 in^3)	175.0	2.11	1898	15.26	57	749	3264	56.21	48	171
Post-transplant container diameter										
Small (15 cm, 6 in)	NA[z]	NA	1426	10.76	69	1031	2100	36.33	58	161
Large (20 cm, 8 in)	NA	NA	1637	13.09	70	1094	3141	61.43	71	243
Significances[y]										
Plug cell volume (PV)	***	***	***	***	***	** *	***	***	***	**
Post-transplant container diameter (PT)	NA	NA	NS	*	NS	*	**	***	NS	***
PV × PT	NA	NA	NS	NS	NS	NS	NS	NS	NS	NS

[z]NA: Not applicable.

[y]NS, NA, *, **, ***: Non-significant, not applicable, or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Table 4. **Leaf area (LA) and shoot dry weight (SDW) at 0, 35, and 107 days after transplanting (DAT), and shoot net assimilation rate (SNAR) and shoot relative growth rate (SRGR) between 0 and 35 DAT or 35 and 107 DAT of *Schizachyrium scoparium* as influenced by plug cell volume and post-transplant container diameter.**

	0 DAT		35 DAT				107 DAT			
Treatments	**LA (cm^2)**	**SDW (g)**	**LA (cm^2)**	**SDW (g)**	**SNAR ($g/cm^2/d)10^5$**	**SRGR ($mg/g/d)10^4$**	**LA (cm^2)**	**SDW (g)**	**SNAR ($g/cm^2/d)10^5$**	**SRGR ($mg/g/d)10^4$**
Plug cell volume										
Small (22 cm^3, 1.4 in^3)	69.7	0.31	488	5.21	68	661	1291	40.53	86	625
Large (84 cm^3, 5.1 in^3)	239.0	1.16	1666	12.03	44	572	1723	39.86	69	348
Post-transplant container diameter										
Small (15 cm, 6 in)	NA[z]	NA	1062	7.34	52	574	1218	34.44	77	480
Large (20 cm, 8 in)	NA	NA	1366	9.90	60	659	1796	45.95	76	492
Significances[y]										
Plug cell volume (PV)	***	***	*	**	**	NS	**	NS	NS	**
Post-transplant container diameter (PT)	NA	NA	*	*	NS	NS	***	**	NS	NS
PV × PT	NA	NA	NS	NS	NS	NS	NS	NS	NS	NS

[z]NA: Not applicable.

[y]NS, NA, *, **, ***: Non-significant, not applicable, or significant at $P \leq 0.05, 0.01, 0.001$, respectively.

Plug cell volume and post-transplanting container size (15 vs 20 cm; 6 vs 8 in diameter) failed to interact in affecting leaf area or shoot dry weight of *Coreopsis* at 35 or 107 DAT (Table 3). Transplanting larger plants from larger plug cells resulted in greater leaf area and shoot dry weight at both 35 and 107 DAT, irrespective of post-transplanting container volume. Thus, larger transplants retained their growth advantage despite lower SNAR and SRGR values between either 0 and 35 DAT or 35 and 107 DAT. Irrespective of plug cell volume, leaf area and shoot dry weight were greater (15 and 22%, respectively) in 20 cm (8 in) than in 15 cm (6 in) containers at 35 DAT. By 107 DAT, plants in larger containers had much greater leaf area (50%) and shoot dry weight (69%) than those in smaller ones. Since post-transplanting SNAR was unaffected by post-transplanting container size, greater shoot dry weight in larger containers must have resulted from greater total photosynthesis from larger leaf area, and not from greater photosynthetic efficiency. Larger supplies of available water and nutrients also may have contributed to greater growth in larger containers.

Similarly to *Coreopsis*, large volume plugs resulted in greater *Schizachyrium* leaf area and shoot dry weight (3.4- and 3.7-fold, respectively) than small plugs at time of transplanting (Table 4). By 35 DAT, plants from large plugs retained their growth advantage, with greater leaf area (241%) and shoot dry weight (131%), despite lower SNAR and SRGR values between 0 and 35 DAT. By 107 DAT, leaf area of plants from large plug cells were 33% greater than those from small plug cells, but shoot dry weight was unaffected by plug cell volume. Between 35 and 107 DAT, plants from large plug cells underwent considerably less growth than plants from small plugs cells, as reflected in the lower SNAR and SRGR values for plants in large plug cells. Irrespective of plug cell volume, larger post-transplanting container diameter led to greater leaf area and shoot dry weight at both 35 DAT (29 and 35%, respectively) and 107 DAT (47 and 33%, respectively), even though neither SNAR nor SRGR was affected between either 0 and 35 DAT or 35 and 107 DAT. Thus, following transplanting, greater volume of growth medium favored greater growth, presumably as a consequence of greater supply of water and nutrients. Our results agree with those of others that larger post-transplanting containers result in greater shoot growth (2, 9), although Keever et al. (9) determined that optimal depth was species specific according to natural root mass morphology. Upcanning from plugs into an intermediate container size before market size, a practice that promotes growth in some species (2), would appear to be unnecessary for *Coreopsis* and *Schizachyrium*.

We conclude from this experiment that the greatest shoot growth of *Coreopsis* and *Schizachyrium* can be achieved by using large plugs cells and large post-transplanting containers. Larger plugs cells resulted in larger plants and this growth benefit was additively retained up to 107 DAT by transplanting into larger containers, responses that can be attributed to greater supplies of water and nutrients than occur in smaller plug cells or post-transplanting containers.

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