Reducing Weeds in Ornamental Groundcovers under Shade Trees through Mixed Species Installation

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Summary. Six durable but slow-to-establish groundcover species, and three fast-growing but short-lived groundcover species, were planted singly and in paired combinations under mature landscape trees to test for relative weed suppression. Installations were replicated on an urban site and a rural site, monitored for two growing seasons, and weeded periodically by hand. All weeds were dried and weighed, and subplot averages (160 observations) for each plant combination were tested by analysis of variance. Weeds were significantly fewer and smaller in the mixed species than in single species subplots. Weed biomass was also significantly less in monospecific groundcover subplots than in unplanted control plots. These results suggest that reduced maintenance cost (and input) for weed control, along with better initial coverage appeal of the paired plantings, may increase marketability of perennial groundcovers.

Along with the recent surge of public interest in herbaceous perennials, landscape use of nonturf groundcovers is increasing, both in sun and shade conditions

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(Ingels, 1997). However, the relatively slow establishment (and higher initial cost) of durable, shade-tolerant groundcovers, compared to the rate of turf seedling or sod establishment, remains a major perceived disadvantage in sales, design, and maintenance. Often, the most attractive groundcovers are those that grow slowly at first, and require hand-weeding or herbicide application for one or more seasons before cover is fully established (Ingels, 1997). This is a major deterrent to consumer and designer choice, and therefore to industry promotion and production of useful groundcover alternatives to turf grasses, especially for use under established shade trees.

Shade trees are essential to the urban landscape, providing a wide spectrum of environmental benefits and human comfort (Gardner and Sydnor, 1984; Gilbert, 1989; Souch and Souch, 1993). However, maintenance of the ground surface below these trees due to shading, and sometimes to root competition, is often a problem for both landscape professionals and for homeowners (Hodel and Pittenger, 1994; Sommer and Cecchettini, 1992). A weed-free surface is required. Ground treatments are either living (turf, shrubs, annual plantings, or perennial groundcovers) or nonliving (organic mulches such as bark chips, and inorganic materials such as gravel or fabric). Mulch installations, whether bark, stone, fabric, or any other nonliving materials, look their best on the day of installation. All mulch covers deteriorate both steadily and inevitably, due to erosion and transport, decomposition, weed establishment, or absorption into the substrate, until time of replacement. Living groundcovers, on the other hand, have the potential to increase in durability and beauty for many years. Although turf is often the automatic choice for groundcover, because of rapidity of establishment and familiarity of maintenance, grasses are often unable to flourish, or even to survive, with reduced light and root competition from trees (Gardner and Taylor, 2002; Quigley and Platt, 1996).

Mixed plantings of two (or more) perennial groundcovers, one ephemeral, one permanent, may fill the need both for rapid, more weed-free establishment and for long-term reliable cover. Such pairs or mixes of groundcovers may provide a customized treatment that will respond to particular micro-site differences. In theory, visual appeal should be acceptable from the day of installation, during establishment, and as the more ephemeral groundcover is replaced by the long-lived species. The principal objective of this study was to compare weed biomass in plots with single groundcover species to weed biomass in paired plantings, over two growing seasons. Additional influences included relative shading of the plots from existing tree canopies, and urban versus rural settings.

Methods and materials

To increase replication, two contrasting sites were selected, and the complete treatment installed at each. One site was the oval promenade on The Ohio State University (OSU) campus in Columbus (shade with high pedestrian traffic); the other was the shade tree demonstration plot (shade with no traffic) at the Secrest Arboretum, Wooster, Ohio (Gardner and Sydnor, 1984, 1987). Between sites, mature trees (more than 35 years old) (Table 1) were paired by canopy density, and by species when possible. Nine groundcover species were chosen in two categories, based on their familiarity, ornamental value, commercial availability, and reliable hardiness in central Ohio, USDA zones 4 and 5, on neutral to somewhat acidic soils. The first category was comprised of fast species: plants with rapid establishment and good summer appearance, but relatively short-lived and with poor winter appearance, carpet bugle (*Ajuga reptans*), sweet woodruff (*Galium odoratum*) and labrador violet (*Viola labradorica*) (Heriteau and Cathey, 1997; Still, 1994). The second category was labelled slow: handsome, evergreen and durable groundcovers once established, but that generally take several seasons to knit fully together, bearberry (*Arctostaphylos uva-ursi*), lily-turf (*Liriope spicata*), english ivy (*Hedera helix*), st. john's wort (*Hypericum calycinum*), japanese spurge (*Pachysandra terminalis*), and periwinkle (*Vinca minor*) (Dirr, 1998; Heriteau and Cathey, 1997; Still, 1994).

Under 10 mature trees at each site, a 9.8 × 9.8-ft (3-m) plot was marked into nine equal subplots, the center square containing the tree trunk. The plots were manually cleared of all existing weedy plant material, but no pre-emergent herbicide was applied. Weed seed load was presumed to be similar among plots. All treatment and control subplots were randomly located under the ten trees at the first site, and each entire plot was then replicated at the second site under trees matched for size, shade, and where possible, species or cultivar. Light was measured under each tree in the first season, on 23 and 24 June 1999, with a light meter (LI-

Table 1. Relative shade under mature trees in replicated plots at each site, underplanted with groundcover pairs and monocultures. Where species could not be paired between sites, trees with similar shade levels were paired for treatments. Light readings were taken with a light meter (LI-191SB; LI-COR Inc., Omaha, Neb.) in late June under maximum leaf area.

Relative shade[z]	Oval on Ohio State Univ. main campus, Columbus	Shade tree trials at Secrest Arboretum, Wooster, Ohio
Medium	Shingle oak (*Quercus imbricaria*)	Ginkgo (Ginkgo biloba)
Medium	Hardy rubbertree (*Eucommia ulmoides*)	Sweetgum (Liquidambar styraciflua)
Light	Green hawthorn (*Crataegus viridis*)	Green hawthorn
Dense	Littleleaf linden (*Tilia cordata*)	Littleleaf linden (T. cordata 'Bicentennial')
Medium	Red maple (*Acer rubrum*)	Freeman maple (*A. ×freemanii* 'Autumn Blaze')
Light	Redbud (*Cercis canadensis*)	Washington hawthorn (*Crataegus ×vaughn*)
Medium	Hackberry (*Celtis occidentalis*)	Hackberry
Dense	Linden (*Tilia* spp.)	Silver linden (*T. tomentosa* 'Sterling')
Light	Kentucky coffeetree *Gymnocladus dioicus*	Kentucky coffeetree
Dense	Sugar maple (*Acer saccharum*)	Sugar maple (*A. saccharum* 'Endowment')

[z]Relative shade levels of light, medium, and dense correspond to light readings of 45,000 to 55,000 lx, 23,000 to 37,000 lx, and 5,000 to 17,000 lx, respectively (1 lx = 0.09 fc). Full sunlight at lat. 40° N can range between 32,000 and 100,000 lx (T.D. Sydnor, personal communication).

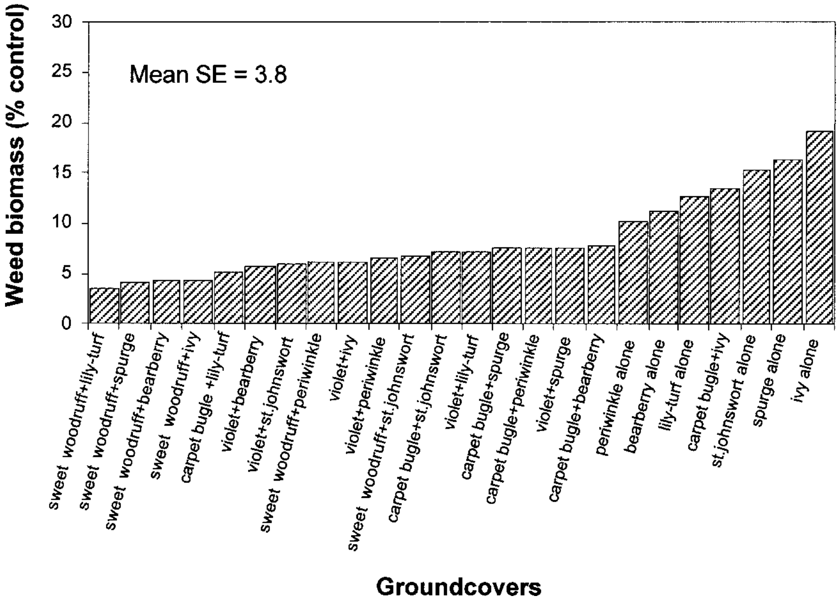

Fig. 1. Ratio of mean weed biomass per treatment subplot to mean weed biomass of control subplots, for first year only. Control = 96.1 g (3.39 oz) dry weight, N = 160.

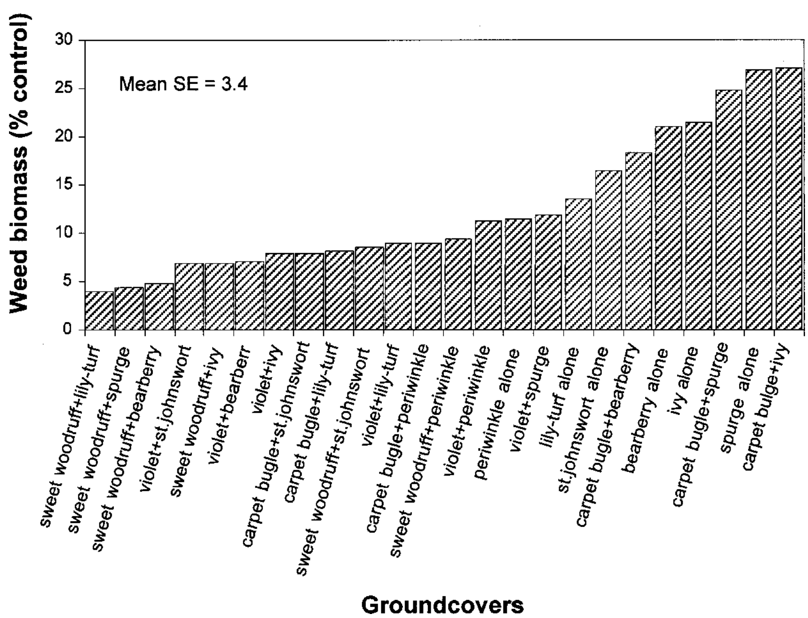

Fig. 2. Ratio of mean weed biomass per treatment subplot to mean weed biomass of control subplots, averaged over both years. Control = 115.03 g (4.057 oz) dry weight, N = 160

191SB; LI-COR, Omaha, Neb.), and four readings averaged for each tree. The trees were grouped into three categories of shade intensity (Table 1). Treatment subplots were planted with 36 plants, 8 inches (20.3 cm) on center both ways, in 6 × 6 equal rows. Holes were dug with a 4-inch (10.2-cm) power auger, through a framed wooden planting guide, to ensure uniformity of spacing. Control subplots were also drilled with the auger to simulate conditions in the treatment plots, by exposing the same amount of seed-bank propagules. Soil at the Wooster site was Wooster silt-loam (6.9 pH), and on the OSU oval was a neutral to slightly acidic (6.8 pH) urban conglomerate, with a mostly silty texture. Commercial ground peat was applied 1 inch (2.5 cm) deep to all plots, treatment and control, and worked in to a minimum depth of 2.5 inches (6.35 cm) to improve moisture retention.

Plants were obtained in April 1999, from several commercial nurseries. Carpet bugle, ivy, spurge, violet and periwinkle, all in 2.5-inch cell-packs [10 inch^3 (163.9 cm^3) volume] came from Gilson Gardens, Perry, Ohio. Bearberry, sweet woodruff and lily-turf, all in 3.25-inch (8.26-cm) pots [37 inch^3 (606.3 cm^3)], came from Hortech, Inc., Spring Lake, Mich. St.john's wort in 2.5-inch cell-packs (10 inch^3) came from Classic Groundcovers, Athens, Ga. Secrest plots were planted on 2 and 3 May and Columbus plots on 5 to 7 May 1999. Before planting, all plots, including the controls, were weeded by hand, and a 0.5 inch (1.27 cm) layer of commercial shredded peat was worked slightly into the soil surface. Plants were set into uniformly drilled holes, using a wooden frame to control spacing. Control plots, though not planted, were drilled just as the treatment plots to ensure similar depth of soil disturbance. Although commercial installations would normally receive organic mulch after planting, no additional surface mulch was applied, so that the existing soil seed bank was unsuppressed. Plants were watered in, and subsequently received less than 0.5 inch/week of water, applied by hand at intervals of 10 to 14 d until mid-September. There was no irrigation system at either site, and central Ohio experienced moderate to severe drought conditions for the entire growing season (Dreitzler, 1999).

Number of plants totalled 5,184 in the nested split-plot model for the whole experiment. The statistical model was based on 80 subplots per site randomly distributed among the 10 trees. At each site there were 3 replications of 18 paired (fast plus slow) groundcover blocks and 6 single species (slow only) blocks, plus 8 control blocks. The number of observations (N) was 160. At 1, 3, and 5 months the first season, and at 12, 14, and 16 months in the second year, each plot was thoroughly weeded by hand. All weed shoots (stems and leaves) for each subplot were bagged, dried for 7 d at 140 °F (60 °C), and weighed.

For this nested, split-plot experimental design, the null hypotheses was that there would be no difference in weed biomass or in groundcover mortality among subplots with single (slow) species plantings, subplots with paired combination of groundcovers, and the control subplots. Analyses of variance and *t* tests (LSD) (SAS, 1993) were performed on weed biomass data for individual years and for both years. Post hoc tests on homogeneous subsets included Student-Newman-Keuls and contrasts among groups, pairs and individual species. Additional hypotheses were that there would be no difference in groundcover mortality or weed biomass

Table 2. Results of the tests of contrasts among slow and fast groundcover species, for both weed biomass (average of 2 years) and groundcover mortality (first year only).

	Weed biomass		Mortality	
Groundcover	**F**	**$P > F$**	**F**	**$P > F$**
Fast versus control	742.66	<0.0001*	29.12	<0.0001*
Slow (alone) versus control	488.13	<0.0001*	20.23	<0.0001*
Slow (mix) versus control	750.12	<0.0001*	28.91	<0.0001*
Slow (alone) versus slow (mix)	8.82	0.0038*	0.11	0.7358

*Significant at $P = 0.05$.

between the two sites, no differences attributable to the level of canopy shade, and no effects of interaction between site and shade level, and between site × shade level × individual tree species.

Results and discussion

Tests of interactions were run, both for first year data and averaged over both years, for weed biomass and mortality, for the effects of site and shade level, site and groundcover species, site × shade × groundcover species, and shade (site × tree species) (Table 2). For both variables, interaction was not significant between site × canopy shade, site × groundcover species or for canopy shade × groundcover species. However, the three-way interaction of site × canopy tree species × groundcover was significant for both weed growth and for mortality.

All groundcover plantings suppressed weed germination and growth to some degree, compared to the unplanted controls (Figs. 1 and 2). In the first year, weed biomass in groundcover plantings ranged from 5% to 20% that of the control plots ($F = 19.42$, $P < 0.0001$) (Fig. 1). Even more significantly in both years, those subplots with paired groundcovers generally had less than half the weed biomass than did the subplots with only slow groundcovers ($F = 12.30$, $p = 0.0009$) (Figs. 1 and 2). Mean weed biomass in only one paired planting, carpet bugle and ivy, was similar to that in the monospecific subplots in the first year (Fig. 1). In the second year, these differences in weed quantity between paired and monospecific treatments, while still statistically significant, were less in absolute terms. Averaged over both years, the weeds in groundcover treatments ranged from 5% to just over 25% the weeds in the controls ($F = 20.07$, $P < 0.0001$) (Fig. 2). The change in second year results may be attributed to suppression of weed growth as the groundcover species increased in size, and to some effect of the groundcover mortality from the first year. Also, had there been normal precipitation for the first growing season, it is likely that all weed biomass values would have been much greater. Tests of contrasts (Table 3) confirm the hierarchical difference of effect in weed suppression among the levels of treatment.

Canopy shade negatively affected weed biomass ($F = 6.78$, $p = 0.001$). Weed weight was inversely proportional to relative degree of canopy shade for both years. Plots under linden (*Tilia*) cultivars, which had the densest shade (Table 1), had almost no weed growth in either year. In contrast with effect of relative canopy shade, the effect of site (secrest versus oval) were not consistent. In the first year, there was no difference in weed biomass between the two sites ($F = 0.01$, $p = 0.91$). However, in the second year there was significant difference ($F = 6.81$, $p < 0.01$), possibly due to greater groundcover survival of the Secrest plots.

Groundcover mortality and survival were affected by site (Table 2). For congruence with the other figures, mortality data are presented for the groundcover combinations (Fig. 3). There was a significant and independent difference in mortality by individual species ($F = 12.09$, $P < 0.0001$). Survival was generally good for the slow growing groundcovers except bearberry, and for the fast growing groundcovers except sweet woodruff (Fig. 3). Although it was the smallest of the plants at installation, lily-turf had 100% survival at both sites, as did myrtle and violet. Bearberry had the highest mortality of all species; as it had the largest initial plant size of all the material, it is unlikely that initial size at planting was the main determinant of survival. The first summer was extremely hot and dry (Dreitzler, 1999), beginning just at the time of the installation. Therefore, some groundcover death was not surprising. There was a mortality effect of site alone. There was trampling damage, both pedestrian and vehicular, on several of the oval plots; at the Secrest plots the only observed damage was some nonfatal mowing of plot edges. There was also an effect of shade level (site × tree species), but there was no effect from other interactions (Table 2). All groundcover plants that survived the first year flourished in the second. Labrador violet and carpet bugle survived better under dense shade, while for japanese spurge there was no

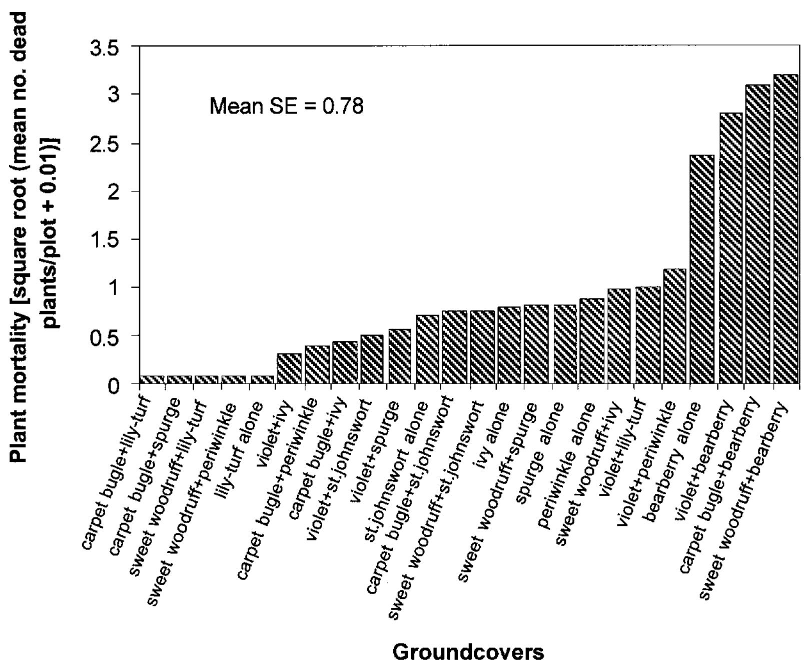

Fig. 3. First year mean plant mortality within subplots for all groundcover combinations. Means (plus 0.01) were square root transformed for data to meet the assumptions of normality; N = 160.

Table 3. Results of the tests of interactions, for both weed biomass (average of 2 years) and groundcover mortality (first year only).

Interaction	Weed biomass F	Weed biomass $P > F$	Mortality F	Mortality $P > F$
Site	1.21	0.2788	30.70	<0.0001
Site × shade level	1.07	0.3524	0.96	0.3904
Site × groundcover	1.39	0.1822	0.95	0.5442
Site × shade × groundcover	0.62	0.9017	0.97	0.5255
Shade (site × tree species)	2.72	0.0075*	2.48	0.0138*

*Significant at $P = 0.05$.

difference attributable to canopy shade.

These results suggest an effective solution to the perceived difficulty of desirable groundcovers being slow to establish and to suppress weed growth. There are many proven hardy, perennial, shade-tolerant groundcovers available to the landscape industry, but their use in landscape design and installation is often avoided because of the time required to establish a weed-free stand and the ephemeral nature of some herbaceous covers. Ironically, although turfgrass can be established within a few weeks, and more economically than any other treatment, its subsequent maintenance is the most expensive component of all managed landscapes (Hensley, 1994). Unfortunately, landscape and garden design books and nursery catalogues do not generally warn the designer or consumer that a recommended groundcover species may take three or more years to establish a continuous, relatively weed-free cover (Heriteau and Cathey, 1997). In fact, usually no distinction, either within or among hardiness zones, is made between short-lived or long-lived perennial groundcovers. Sun and shade tolerance and moisture and soil texture requirements are often the only characteristics listed. However, the fastest groundcovers to establish may not be very dense, durable or long-lived. In USDA climate zone 5 carpet bugle is a good example of such a cover: while attractive and initially fast to establish, it often suffers from crown rot in summer and from winter die-back (Still, 1994). A very long-lived groundcover such as bearberry, in contrast, takes several years to become a solid cover, but is thereafter very durable (Dirr, 1998), as is japanese spurge (Still, 1994). Another potential application of combined groundcovers would be to plant an entire area with the slow species at 1.5 to 2 times normal spacing, and to interplant in ribbons or sweeps of two or more fast species, choices for which could vary with topography, soil conditions, or light level. Public reaction to mixed-species groundcover plantings, as it has been to some prairie gardens, may be that they look weedy. This subjective reaction may be based on an agricultural heritage: we are accustomed to single species plantings whether in production or in ornamental landscapes. However, our results suggest that combining ornamental species will promote faster, more effective coverage, an undeniable advantage in site maintenance.

For both ornamental woody plants and orchard trees, groundcover plantings may be superior to either mulch or to bare ground. Too much mulch can retard root-zone warming in spring, and may negatively affect tree growth (Greenly and Rakow, 1995); excessive mulch can also promote fungal growth (Brantley et al., 1997). In addition to their aesthetic value, where shade precludes use of turfgrasses or where mulching is not practicable, groundcovers can benefit the trees themselves. Living groundcovers may enhance cold hardiness and reduce woody plant losses to winter injury (Calkins and Swanson, 1998).

Long-term maintenance of established groundcovers will always include some kind of weed control. Spring application of pre-emergent herbicide may reduce weed germination significantly. It is also possible to mow mature groundcover stands, both to control the growth of invasive woody species without hand weeding, and to rejuvenate senescent patches of the groundcover itself (Hodel and Pittenger, 1994). A more diverse plant community, even at a small scale, is generally more sustainable and resistant to disturbance or invasion than is a monoculture (Gilbert, 1989; Quigley and Platt, 1996). Combinations of slow-growing, persistent groundcovers with faster growing, more ephemeral species, may effectively reduce the level of maintenance normally necessary for the establishment of slower species. An additional benefit to groundcover design, marketing and installation may be the promotion of site-specific, customized combinations of two or more perennial groundcovers.

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