Establishment and Persistence of Field Sown North American Prairie Grasses in Southern England in Response to Mulching and Extensive Weed Management[1]

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Abstract

Establishment and management of North American prairie grasses by field sowing was investigated at the Royal Horticultural Society Garden at Wisley, Surrey, in Southern England. Untreated seed of little bluestem (*Schizachyrium scoparium* (Michx.) Nash); indian grass (*Sorghastrum nutans* (L.) Nash); and prairie dropseed (*Sporobolus heterolepis* (A.Gray) A.Gray.) was sown in May 1997 at 550 seeds/m^2 onto topsoil plots (control), topsoil with charcoal mulch, and topsoil covered with transparent, perforated crop polyethylene post sowing. Highest percentage emergence was recorded in the clear polyethylene mulch followed by the charcoal mulch. Weed competition was managed by cutting to 75 mm (≅ 3 in) above the soil surface. Dry weight of prairie grass seedlings in October 1997 was strongly negatively correlated with percentage weed cover in June 1997. Despite the weed competition, on plots where sufficient seedlings survived, *Schizachyrium* and *Sorghastrum* were eventually able to dominate *Agrostis stolonifera*, the most abundant weed, when burnt annually in April. No regeneration of prairie grasses from self-sown seed was observed within the experimental treatments over an 8 year period. The application of this research to more sustainable horticultural practice in urban landscapes is discussed.

Index words: seed, urban landscapes, sustainability, establishment, management, mulches.

Species used in this study: little bluestem (*Schizachyrium scoparium* (Michx.) Nash); indian grass *(Sorghastrum nutans* (L.) Nash); prairie dropseed *(Sporobolus heterolepis* (A.Gray) A.Gray).

Significance to the Nursery Industry

Local government budgets for planting in urban landscapes have declined over the past two decades and with this the extensive use of horticultural plantings. Sustainability initiatives have focused interest on new forms of urban planting that consume fewer resources in both the short and long term than those based upon container grown nursery stock. Within herbaceous plantings, native wildflower meadows sown *in situ* are becoming increasingly popular as an alternative means of providing 'seasonal color'. Wildflower meadows are inexpensive to establish, have high habitat value and can be used on a large scale. Research at the University of Sheffield over the past decade (7) has investigated whether it is possible to establish ecologically based, sustainable communities of horticultural as well as native species by field sowing. The former are used to lengthen the flowering season, or provide visual or functional effects not possible with our numerically small (1500 species), primarily spring to early summer flowering native flora.

Introduction

During the past decade there has been an upsurge of interest in the use of ornamental tussock forming grasses in designed urban landscapes throughout the western world (5). Many tussock grasses are robust plants that provide, even in many winter deciduous species, year round structure, texture and color. They are typically unpalatable to slugs and snails (the major herbivores of urban herbaceous plantings in England) and hence tend to persist even at low levels of maintenance. Tussock grasses differ from lawn or meadow grasses in that they form a distinctive discrete foliage clump, and typically do not undergo post flowering, mid-summer leaf senescence, remaining tidy and attractive from late spring to autumn. In urban landscapes tussock grasses can be used as ground cover monocultures or combined with forbs to create colorful, species rich, meadow or prairie-like plant communities.

A number of visually striking tussock grasses originate from the North American prairie. Most of these grasses are warm season species with C4 metabolism. North American prairie grasses are far more drought tolerant than the most widely cultivated native British tussock grasses, *Deschampsia cespitosa* and *Molinia caerulea*, both of which are C3 grasses of moist habitats (19). Prairie grasses have potential for use in urban landscapes in southern England, where severe droughts are increasingly common, causing many C3 grasses to become senescent and unattractive. Prairie grasses retain attractive foliage when drought stressed, removing any need for irrigation and also minimizing the risk of spontaneous or deliberately lit grass fires. These traits make prairie grasses potentially highly sustainable; not only because they have low resource requirements but also because by remaining green under severe drought conditions they are likely to be more positively perceived by the urban public.

A substantial number of introduced grass species have become significant environmental weeds in many parts of the world. Reliably predicting which non-native species pose a threat is extremely difficult; however, high capacity to spread by seed and rhizomes (24) and being well fitted to the climate of the cultivation site are recurring factors. Some prairie grasses are intrinsically more invasive than others;

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Panicum virgatum is an aggressive self-seeder (5), where as slow growing, ecologically 'conservative' species such as *Sporobolus heterolepis* are not invasive. C3 grasses are more competitive than C4 grasses at latitudes > 45° N (1). England lies between 51 and 56° N which suggests that prairie grasses are likely to be poorly fitted to the cool summer climate. There are few records of naturalised C4 perennial grasses and no records of prairie grasses in England (20) despite over 100 years of cultivation in gardens. At present, prairie grasses seem highly unlikely to pose a significant threat to semi-natural vegetation.

The cost of establishment by planting has precluded the use of extensive swards of tussock grasses in public parks and commercial landscapes in England, despite the fact that naturalistic vegetation is currently in vogue (7). In North America, techniques have been developed to establish native tussock grasses from seed sown *in situ* rather than by planting (14). These low cost techniques are a pre-requisite for the application of these vegetation types to larger scale urban landscapes.

Given that establishing horticultural vegetation by sowing seed *in situ* is likely to be most attractive where budgets are insufficient to use planting, it is unlikely that conventional weed control practice will be possible under such circumstances. Without some reduction in the intensity of weed competition however, on productive soils establishment of sown species is typically greatly reduced (3) and hence effective, yet resource extensive weed control practices are required. Many C4 grasses are able to detoxify triazine herbicides such as atrazine (11) but these herbicides can no longer be used in urban England. Hence weed management techniques such as mowing and burning need to be investigated. As pressure grows to develop more 'sustainable' horticultural plantings in urban landscapes, there is a need to reassess the degree to which such plantings can tolerate competition at key points in their lifecycle, yet still develop satisfactorily.

Most North American prairie grasses require relatively high soil temperatures (generally > 20C) for successful germination, emergence and establishment (12). Prairie grasses do however vary considerably both between species and ecotypes of a species in terms of optimum temperature requirements for germination and emergence (18). *Sorghastrum nutans* is a C4 grass that germinates and emerges at relatively low soil temperatures (12). Warm season prairie grasses also differ from cool season meadow grasses in that although highly drought tolerant once established, they are more intolerant of moisture stress during germination and emergence (13, 21).

This requirement for high soil temperatures for germination poses problems for establishment by field sowing in England where summer soil temperatures are typically 5–7C (41–45F) lower than those experienced in the prairie regions of the United States (2, 26). To increase soil temperatures while soils are moist enough for germination, mulching between crop plants with clear and black polyethylene has been employed (25). Raj and Kapoor (22) recorded temperatures as high as 52.2C (125F) under 25 μm clear polyethylene mulch.

Soil temperatures have also been artificially elevated by non-sheet mulches that decrease soil albedo. Soil temperatures under asphalt and bitumen emulsions are similar to those under clear polyethylene (25). Mulches of coal fines, and burning surface debris to blacken the soil surface have been used to elevate soil temperature and increase emergence of *Themeda triandra*, a C4 grass (16). Surface blackening also has a significant long term impact on competition between species and long term persistence. C4 grasses typically dominate C3 grasses and forbs when burnt in spring as they largely escape defoliation at this time of year and are better able to respond to increased soil temperatures (23).

The overall aim of this research was to investigate the establishment and long term persistence of three North American prairie grasses in monoculture by field sowing in Southern England within a low intensity maintenance regime. This study is part of a larger research programme to investigate the feasibility of creating sown communities of North American prairie grasses and forbs as a less resource intensive alternative to traditional herbaceous planting in urban parks in England.

Materials and Methods

The experiment was undertaken at the Deers Farm Experimental Station, Royal Horticultural Society's Garden, Wisley, Surrey, England (51:18:59 N, 0:28:24 W, altitude 15 m). In the context of the British Isles as a whole, summers in Surrey are warm, but cooler than those of continental landmasses at the same latitude. A comparison of the thermal climate, and rainfall characteristics of the research site with Madison, Wisconsin, is given in Table 1. The soil is a well-drained loamy sand (Shanwick series) of pH 5.75, prone to severe drought and relatively infertile; N = 3.66 ppm (available NH_4 and NO_3), P = 68 ppm (available), K = 268 ppm (available). No nutrients were added immediately prior to or during the experiment.

Three prairie grass species, little bluestem (*Schizachyrium scoparium*); indian grass (*Sorghastrum nutans*) and prairie dropseed (*Sporobolus heterolepis*), were chosen for the study on the basis of attractive appearance during the growing season, striking autumn color, commercially available seed and high tolerance of summer drought and acidic soils. The three species also represent a gradient in terms of growth rate and ultimate size. None of these species are considered to be invasive in Northern Europe. The species are naturally distributed across the Midwest of North America, from southern Canada to Texas. Seed of a northern population was obtained from Prairie Nursery, Westfield, WI (43:53:01 N, 089:29:36 W, altitude 260 m).

The experimental area was sprayed with a glyphosate herbicide in April 1997 to control perennial weeds prior to cultivation. At the time of sowing the experimental site was free of seedling weeds. There was however evidence of re-growth from surviving rhizomes of the dominant weeds on the site; *Agrostis stolonifera*, *Erodium circuatum*, and *Rumex acetosa*.

A completely randomized block design with 9 treatments (3 prairie grass species × 3 mulch treatments) replicated 5 times was adopted. Each treatment plot was sown with only one species of prairie grass and measured 900 × 900 mm (0.81 m^2) and was surrounded by 600 mm wide cross paths. The three different mulch treatments were sow into site topsoil (control), sow into charcoal mulch, and sow into topsoil and cover with clear perforated crop polyethylene mulch. The assessment unit in the experiment was the entire plot.

The plots were sown on May 5, 1997, with 445 seeds of each species, the equivalent of 550 seeds/m^2 and raked in. This rate is a typical value used when establishing grass only prairies in North America. Charcoal plots were mulched prior

Table 1. A comparison of precipitation and mean monthly air temperature between Wisley, United Kingdom, and Madison, Wisconsin, USA.

	1998–1999		30 year mean			
	Precipitation (mm)	Air temperature (C)	Precipitation (mm)		Air temperature (C)	
	Wisley[zy]	Wisley	Wisley	Madison	Wisley	Madison
January	10.2	2.3	61	25	4.1	–8.9
February	70.6	6.9	40	23	4.3	–6.2
March	12.3	9.1	51	51	6.3	0.4
April	7.9	9.5	47	69	8.5	7.7
May	18.0	14.5	54	74	11.8	13.9
June	96.6	16.1	50	81	14.8	19.1
July	42.8	19.8	45	81	16.8	21.7
August	82.4	20.2	55	94	16.4	20.2
September	12.1	15.1	58	71	14.2	15.6
October	70.1	10.8	64	48	11.1	9.4
November	68.2	8.5	62	48	6.9	1.9
December	58.0	6.5	63	41	4.9	–5.7

[z]Data abstracted from British Atmospheric Data Centre (2) and University of Wisconsin (26).

[y]Latititude and longitude of these two sites are as follows; Wisley (51.18 N, 0.28 W), Madison (43.05 N, 89.23 W).

to sowing with 10 liters of fine grade charcoal (dust to 5 mm) to achieve an approximate depth of 10mm. Clear perforated crop polyethylene (35 µm) was laid over the polyethylene plots after sowing and held in place by burying the edges of the sheet. The experiment was irrigated post sowing to return the soil to field capacity. The polyethylene mulch was removed on June 16 when it was evident that prairie grasses had emerged.

To reduce the competitive capacity of colonizing weeds, plots were cut over at approximately 75 mm (3 in) with hand shears (to simulate mowing) after the first seedling count on June 19 and the cut material removed from the plots. This procedure was repeated in July and August 1997. Thermocouple probes were placed in control and mulch plots adjacent to the experiment to record soil temperature at approximately 25 mm (1 in) depth.

The number of prairie grass seedlings was counted on June 19, July 29 and September 18. Cover values were estimated on a 0–100% scale for prairie grasses and colonizing weeds. Height of prairie grasses and weeds were also recorded at the three dates previously mentioned, although the latter two recordings were clearly influenced by the practice of cutting. Above ground biomass of the prairie grasses was harvested on October 23, 1997, oven dried, and weighed to establish mass per plant and total mass per treatment plot. In subsequent years, maintenance of the experiment consisted of annually burning the plots in April. This was undertaken using a propane gas fuelled triple burner mounted on a 1.2 m (4 ft) hand lance. This equipment was hired from HSS Tool Hire, Penistone Rd, Sheffield, and allows burning to be employed without raising significant health and safety concerns. Plots were burnt until all above ground tissue both dead and living was carbonised. Immediately prior to burning, an assessment was made of cover values of weed species. Total prairie grass biomass per plot was harvested by cutting at ground level in November 1998, 1999, and 2001, dried and weighed. Final scientific assessment was made in November 2001, however plots continued to be maintained and observed until November 2004.

Statistical analysis. All data from the experiment was assessed for normality and homogeneity of variance using the Kolmogorov-Smirnov and Levene test respectively. Where data was normal or could be normalized by logarithmic (mass and height data) or arcsine square root transformation (percentage data) and variance was sufficiently homogenous, one-way and two-way ANOVA were used, followed by post hoc tests. Interactions are only mentioned in the results when they are significant at $P = 0.05$. Where analysis was undertaken on transformed data, values were back-transformed for presentation. Error bars on charts represent confidence intervals. Where data involved independent samples but could not be normalized, the non parametric Kruskal-Wallis test was used in lieu of a one-way ANOVA, and the Scheirer-Ray-Hare test in lieu of a two-way ANOVA. The Wilcoxon Sign test was used for related samples. Pearson and Spearman correlation tests were used as appropriate. Analysis was undertaken using SPSS version 10 and Genstat 5 Release 4.2.

Results and Discussion

Seedling germination and emergence. Laboratory germination tests on samples of the seed sown in the experiment gave the following results; *Schizachyrium* = 42% (± 1.69), *Sorghastrum* = 22% (± 2.93), *Sporobolus* = 67% (±7.00). Emergence of prairie grass seedlings in the field experiment was evident by June 11, 37 days after sowing. In all species × mulch combinations, emergence increased up to the July assessment (Table 2). The greatest percentage increase in number of seedlings between these two dates occurred in the charcoal plots. With the exception of *Sporobolus* at the September assessment, a one-way ANOVA found statistically significant differences ($P < 0.05$) in the numbers of seedlings present in the three mulch treatments at each assessment date in all species (Table 2). A two-way ANOVA showed that the type of surface mulch used had a highly significant effect ($P < 0.001$) on the maximum number of prairie grass seedlings recorded. Prairie grass seedlings were fewest in the control, and most numerous under polyethylene mulch (Fig. 1). Emergence values for polyethylene mulch were in fact similar to those recorded for prairie grass species in a field experiment in Missouri, USA (13). The large disparity between seedling numbers on control and polyethylene plots at the first assessment date (Table 2) plus previous research (12) suggests species can be ranked in terms of dependence

Table 2. **Effect of mulch treatment on number of prairie grass seedlings in 1997.**

Species	Date	Control	Polyethylene	Charcoal	
Schizachyrium scoparium	6/19/1997	15 (± 2.11)a[zy]	85 (± 6.07)b	34 (± 8.16)a	$P < 0.001$
Schizachyrium scoparium	7/29/1997	39 (± 12.36)a	93 (± 6.23)b	63 (± 5.72)ab	$P = 0.003$
Schizachyrium scoparium	9/18/1997	34 (± 11.22)a	73 (± 8.87)b	59 (± 5.98)ab	$P = 0.029$
Sorghastrum nutans	6/19/1997	24 (± 4.47)a	74 (± 9.37)b	35 (± 9.56)a	$P = 0.002$
Sorghastrum nutans	7/29/1997	34 (± 9.50)a	89 (± 13.47)b	64 (± 9.30)ab	$P = 0.010$
Sorghastrum nutans	9/18/1997	35 (± 5.82)a	65 (± 9.47)b	45 (± 5.93)ab	$P = 0.036$
Sporobolus heterolepis	6/19/1997	20 (± 4.95)a	48 (± 9.49)b	16 (± 4.08)ab	$P = 0.010$
Sporobolus heterolepis	7/29/1997	26 (± 4.39)a	72 (± 16.30)b	41 (± 4.16)ab	$P = 0.023$
Sporobolus heterolepis	9/18/1997	19 (± 4.47)a	43 (± 12.10)a	35 (± 4.58)a	$P = 0.135$

[z]Within rows means followed by the same letter are not significantly different at $P = 0.05$ (Tukey HSD).
[y]Values in parenthesis represent 1 SEM (standard error of the mean).

on soil warming for successful emergence as *Schizachyrium* > *Sorghastrum* > *Sporobolus*.

These results must however be considered in the context of the higher than average temperatures experienced in 1997, with mean air temperature in August and September similar to those in Madison, WI (Table 1). August was also atypically wet, and this increased seedling emergence particularly in control plots where germination earlier in the year would have been restricted by low soil temperatures. Lower establishment might be anticipated in a more meteorologically average year. As prairie grass seed is inexpensive (cost at rate used in the experiment was *Schizachyrium* £0.05/m^2 (\$0.07/m^2), *Sorghastrum* £0.09/m^2 (\$0.13/m^2), and *Sporobolus* £0.23/m^2 (\$0.33/m^2)), this could be compensated for in practice by increasing sowing rates without exceeding likely economic thresholds.

The pattern of emergence across the assessment dates suggests that the highest soil temperatures were attained under polyethylene mulch; however; due to an undetected failure in the data logger, soil temperature data are not available for the study. Charcoal mulching also appears to effectively increase soil temperature, and is much more practical for use in public landscapes.

Seedling survival and growth. Seedling numbers decreased in all but one species × treatment combination between July and September (Table 2). A two-way ANOVA undertaken on survivorship data (number of seedlings in September expressed as a percentage of seedling numbers in July) found that mulch treatment had a significant effect on survivorship ($P = 0.017$), with control > charcoal = polyethylene (Fig. 2). *Schizachyrium* showed significantly higher survivorship than *Sporobolus*, with *Sorghastrum* intermediate and not significantly different from either species. Overall, however, survivorship was high, despite the extensive weed cover. Weeds reduce growth of desired plants through above ground shading, and below ground competition for water and nutrients (9), with the relative importance of these two components in determining the outcome of competition varying according to the species involved (30).

Mowing has little effect on alleviating below ground competition for water and nutrients (8). In this study, the main effects of cutting plots at 75 mm (3 in) in June, July, and August were likely to be temporary reduction in competition for light. Mowing is recommended (29) as a means of managing weed competition in newly sown, naturalistic, herbaceous vegetation. O'Keefe (17) found mowing improved first year survival and growth of sown prairie forbs and grasses, however as cutting stimulates dense basal growth in some weeds, across the surface of the plots used in this study, it may have simultaneously increased and decreased competition for light.

High survival of seedlings on the control plots is misleading, and is most likely to result from more seedlings having germinated between the July and September assessment dates, than on charcoal and polyethylene plots. Counts were undertaken too infrequently to separate early and late emerging cohorts, and seedlings counted represent the balance between

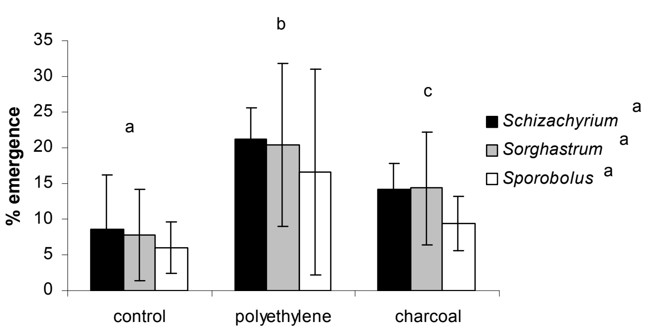

Fig. 1. Effect of mulch treatment on maximum recorded seedling emergence (July 1997) as a percentage of seed sown. Error Bars show Confidence Intervals. Treatments and species followed by the same letter are not significantly different at P = 0.05 (Tukey HSD test).

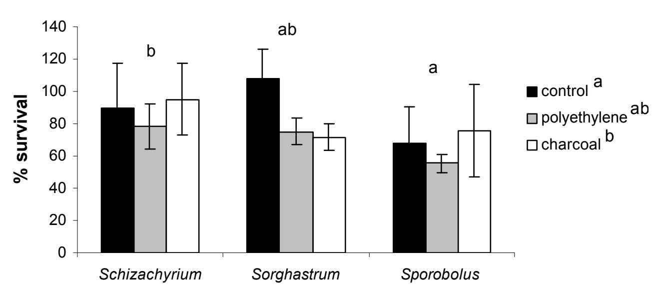

Fig. 2. Effect of mulch treatment on survivorship of seedlings in 1997 (seedlings present in September as a percentage of number present in July). Error bars represent confidence intervals. Treatments and species followed by the same letter are not significantly different at P = 0.05 (Tukey HSD test).

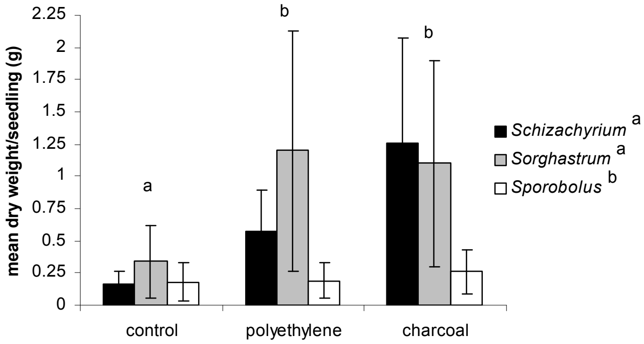

Fig. 3. Effect of mulch treatment on mean dry weight of individual prairie grass seedlings in October 1997. Error Bars represent Confidence Intervals. Treatments and species followed by the same letter are not significantly different at P = 0.05 (Tukey HSD test).

mortality of older seedlings and emergence of new seedlings. The lack of any correlation between prairie grass seedling survival and weed cover in June may be due to new grass seedlings masking the losses resulting from shading by plot weeds. Slug and snail predation is often a major cause of seedling mortality (10) however no signs of this were observed. In common with many stress tolerating grasses (4) the three species studied appear to be unpalatable to molluscs.

At harvest in October 1997, a two-way ANOVA of mean shoot dry weight showed that the prairie grasses growing in charcoal plots were statistically the same size as those on polyethylene plots, while plants in the control were significantly smaller ($P < 0.001$). There were also differences between species (Fig. 3). *Sorghastrum* was the tallest and most vigorous species and *Sporobolus* the shortest and least vigorous. *Schizachyrium* was intermediate, although by the October biomass harvest, seedlings were statistically the same weight as *Sorghastrum*. Cutting at 75 mm (3 in) during establishment to reduce weed competition may have disadvantaged the taller *Sorghastrum* seedlings.

Prairie grass seedlings that emerged after the July assessment date were generally very small in relation to weed species on the plots, and unlikely to survive into the second year. Even if they survived shading by weeds, small prairie grass seedlings suffer high over-wintering losses due to frost heave and water erosion of soil around the root crown (Hitchmough, unpublished data). This restricts using late sowings, for example in July or August, when soil temperatures are warm enough for high germination and emergence, as a means of establishing prairie grasses in England.

Prairie grasses in charcoal plots caught up with the initially larger seedlings in the polyethylene treatment. Charcoal is alkaline (pH 8.75), and raised the pH of the control plots from 5.76 to 6.75, presumably increasing availability of some nutrients. While this may have had some effect, the lower cover values and reduced height of the weeds on the charcoal plots probably had a greater influence. The particularly marked response of *Schizachyrium* is most likely due to locally elevated summer soil and air temperature associated with charcoal mulching. Charcoal mulching also significantly enhanced (Scheirer-Ray-Hare test, $P = 0.013$) flowering of *Schizachyrium* (data not shown). This seems most likely to be due to elevated temperatures in August and September as *Schizachyrium* were no larger on charcoal, than polyethylene plots in October 1997 (T test, $P = 0.111$, ns). The surface of the charcoal plots exceeded 50C on sunny days during August 1997. Charcoal is also a source of potassium and Kalmbacher *et al.* (15) have shown this nutrient to increase reproductive tillering in *Schizachyrium scoparium* var. *polycladus* (Scribn. & Ball.).

Weed cover in the first year. Conyza canadensis, *E. circuatum*, *A. stolonifera* and *R. acetosa* were abundant, establishing from rhizome fragments and the seed bank. At the first assessment date (June 29) weed cover values were significant different ($P < 0.001$) across the mulch treatments (control = 75%; polyethylene = 53%; charcoal = 33%). Cover values decreased at the July assessment due to the practice of clipping over the plots. By September weed cover values were the same in all treatments. Shallow layers of mineral and organic surface debris have been shown to significantly inhibit weed germination in the underlying soil (6, 32). With charcoal mulching these effects are most likely due to decreased light levels at the soil surface. The charcoal may also have acted as a carbon source, increasing microbial consumption of soil nitrogen and reducing growth rate of emerging weeds. Wilson and Gerry (31) describe similar effects in sowings of prairie forbs and grasses when sawdust has been used as a soil amendment.

A Pearson correlation test was undertaken to assess the strength of association between weed cover at the three assessment dates and mean dry weight of prairie grasses at harvest in October. The strongest associations were for cover values at the June assessment: *Schizachyrium* ($r = -0.920$, $P < 0.0001$), *Sorghastrum* ($r = -0.795$; $P < 0.0001$), and *Sporobolus* ($r = -0.688$, $P = 0.005$). Correlation tests were also undertaken on weed cover vs. seedling survival at the three assessments dates, but none were significant. Weed cover in June was however negatively correlated with seedling density in September: *Sporobolus* ($r = -0.695$) and *Schizachyrium* ($r = -0.556$). This correlation was not significant for *Sorghastrum*. Reducing or even just delaying weed competition during the first two months post sowing by deeper layers of charcoal mulches is likely to greatly improve prairie grass establishment. In an experiment carried out on adjacent plots, sown *Schizachyrium* were larger and significantly more numerous ($P < 0.05$) on weeded controls than the weedier treatments (Reid, unpublished data).

Schizachyrium showed the strongest negative correlation between October dry weight and weed cover in June. This may be because it is highly intolerant of shade yet its foliage is essentially basal and subject to shading by neighboring weeds, which in turn will reduce soil temperature. It is naturally associated with short, open vegetation and infertile soils. *Sorghastrum* is a much more productive species naturally associated with taller, less open vegetation. *Sorghastrum* dry weight correlates less strongly to weed cover, presumably because its leaves are attached to erect stems and less likely to be shaded by weeds. *Sporobolus* showed the least association between weed cover in June and dry weight in October. This species is a very slow growing, classic stress tolerator in terms of Grime's (9) CSR (Competitor-stress tolerator-ruderal) model. Accordingly it would be less able to utilize the additional resources associated with lower weed cover values as effectively as the other two prairie grasses. Losses of *Sporobolus* in this study are most likely due to shading by weeds.

Table 3. Mean density of prairie grass seedlings per plot in June 1998.

	Control	Polyethylene	Charcoal	
Schizachyrium scoparium	17.8 (52.3%)[z]	43.2 (59.1%)	35.0 (59.3%)	$P = 0.084$ ns
Sorghastrum nutans	28.2 (80.5%)	62.8 (96.6%)	35.8 (79.5%)	$P = 0.077$ ns
Sporobolus heterolepis	1.8 (9.4%)	14.0 (32.5%)	12.2 (34.8%)	$P = 0.042$

[z]Values in parenthesis represent 1998 values as a percentage of those in 1997.

The warmth of the growing season is likely to mediate the effect of weed competition on the establishment of prairie grasses in England, particularly with highly temperature responsive species such as *Schizachyrium*. Sowings of the same Wisconsin *Schizachyrium* population in Sheffield, (approximately 300 km further north), have generally failed. Seedlings establish, but grow very slowly and are displaced by year 2 by more competitive neighbours (Hitchmough, unpublished data). Phan and Smith (18) found more southerly populations of this species fail to establish in Southern Manitoba, at the northern edge of this species range.

Growth and development during years 2–5. The numbers of prairie grass seedlings on the plots declined between September 1997 and June 1998 (Table 3). Seedling survival was highest in *Sorghastrum* and lowest in *Sporobolus*. Charcoal and polyethylene mulching significantly increased the number of seedlings of *Sporobolus* ($P = 0.042$) that survived. Foliage and inflorescence biomass (as dry weight) continued to increase to November 2001 with *Sporobolus* (Fig. 4) remaining the least productive species. Dry weight differences in response to the 1997 mulching treatments were only statistically significant in *Sporobolus*.

Weed cover values for the prairie grass plots (in November 2001) reflected the biomass of the prairie grasses. Where prairie grass biomass was low, weed cover was high, and vice-versa (Fig. 5). At the end of the first year of the experiment (1997), mean weed cover values were in the region of 85–90%. By the fifth year of the study (2001), prairie grass competition and annual spring burning had allowed *Schizachyrium* and *Sorghastrum* to reduce weed cover (mostly *A. stolonifera)* to mean values of 30%, with many plots <10%. The experimental plots were maintained till November 2004 (year 8) by which time it was evident that a degree of equilibrium had been achieved between horticultural and weed species. *Agrostis* grew actively in late autumn and spring when the prairie grasses were dormant, then declined in summer as the soils dried out and the prairie grasses developed. *Sporobolus* was insufficiently productive to successfully compete with *Agrostis*, but may be able to do so on a less fertile soil.

Sporobolus differed from the other prairie grasses in that its overall plot dry weight in 2001 was significantly greater and weed invasion significantly lower on charcoal mulched plots. We hypothesize that as the most slow growing species, the benefits provided by reduced weed competition in the first year (1997) 'carried over' (28) into subsequent years, despite not being expressed in significantly greater individual foliage dry weight in that year. In addition, because *Sporobolus* is a slow growing species and less able to shade the ground on plots, its growth after the first year would have benefited more from the capacity of the remnant charcoal mulch to decrease soil albedo and raise soil temperature. The leafier canopies of *Schizachyrium* and *Sorghastrum* would largely negate any soil heating from the charcoal mulch. Support for this hypothesis comes from comparison of *Sporobolus* seedling density on polyethylene and charcoal plots in 1998. Density was slightly higher on the former, but despite this, dry weight on the charcoal plots was significantly greater by November 2001.

Although mulching in 1997 did not have a statistically significant impact on dry weight and % weed cover in *Schizachyrium* and *Sorghastrum* in 2001, it increased seedling density in all species, and this is often a key determinant of capacity to compete with weeds (27) and hence long term success. This is well illustrated by the extremely strong association ($r = 0.795$, $P < 0.01$) between seedling density in 1998 (mean of all species) and prairie grass dry weight in November 2001. Seedling density × % weed cover gave a value of $r = –0.816$, $P < 0.01$. This suggests that increasing density of prairie grass seedlings through either higher seed rates or reducing mortality through improved initial weed

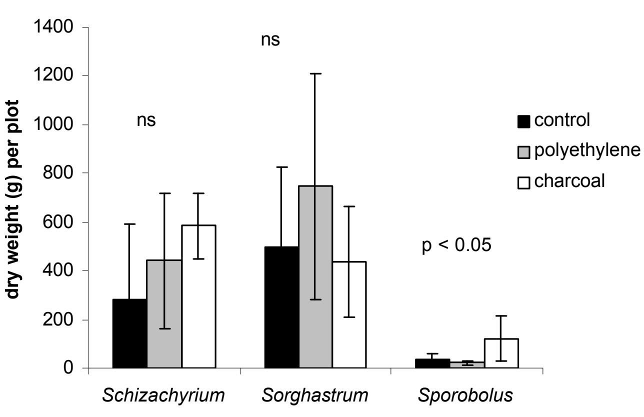

Fig. 4. Effect of mulch treatments in 1997 on biomass of prairie grasses in November 2001. Error bars represent Confidence Intervals. Post hoc values not available due to non-parametric analysis.

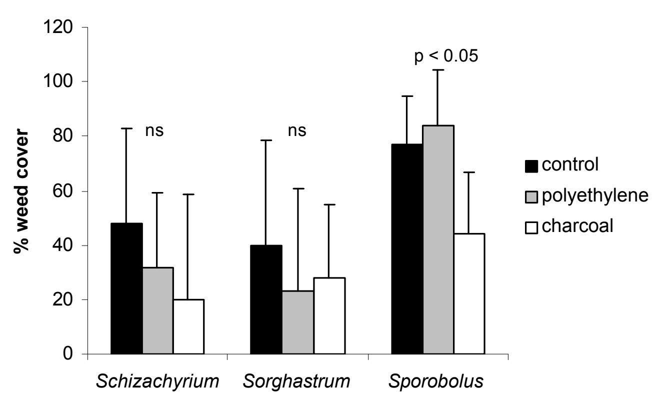

Fig. 5. Effect of mulch treatments in 1997 on % weed cover in November 2001. Error bars represent Confidence Intervals. Post hoc values not available due to non-parametric analysis.

control is likely to have highly beneficial long term consequences. A linear regression undertaken on weed cover data for 2001 (mean of all treatments) gave a value of 52.4 prairie grass seedlings at zero weed cover. Notional density thresholds will be lower for more vigorous, tillering grasses such as *Sorghastrum* and higher for slow growing, weakly tillering species such as *Sporobolus*. The maximum density of *Sporobolus* on any plot in 1998 was 28 plants (corresponding weed cover of 20% in November 2001), too low for effective competition with weeds. Zero weed cover in herbaceous plantings is an unrealistic goal in most low maintenance situations, as there are always temporal and spatial gaps that will be colonized by opportunistic weedy species. High densities of desired species are however, able to reduce weed biomass to levels that allow persistence of the former (27) and also most importantly, allow sown horticultural vegetation to be perceived as sufficiently weed free to be 'attractive'.

Informal discussions with visitors and horticultural staff over an eight year period suggest that plots with approximately 20% or less weed cover were generally perceived to be 'attractive', although this varied depending on the time of year. When the prairie grasses were showing autumn color, plots with higher levels of weed invasion became more acceptable. Greater understanding of these perceptual relationships is required if more sustainable urban plantings are to be successful.

Horticultural species that are able to compete with weedy species offer the possibility of more resource sustainable plantings, even though they may have higher capacity to 'naturalize' beyond the planting site. However, in this study after eight years, no prairie grass species had established by self-seeding in adjacent plots of different species, nor into the sparse turf around the experiment. Prairie grass establishments were confined to an occasional *Schizachyrium* seedling on the annually cultivated cross paths. These grasses seem to have extremely low capacity for naturalization in southern England.

In conclusion, we have shown that it was possible to successfully establish North American prairie grasses by field sowing in southern England, in the presence of weed competition mediated by cutting in the first year, and annual spring burning in subsequent years. Within this management regime, *Schizachyrium* and *Sorghastrum* appear sufficiently well fitted to the climate of southern England to compete with weedy native species. *Sporobolus heterolepis* appears to require lower levels of weed competition to establish satisfactorily.

In cool oceanic climates, mulching with charcoal fines is an effective means of increasing seedling establishment but represents an additional cost (at 2002 prices) of approximately £1.83/m^2 (\$2.59/m^2). Managing weeds in sown horticultural vegetation by mowing and burning as opposed to hand weeding is attractive because it is within the scope of the most unskilled and poorly funded landscape management agencies. Management more demanding than this is increasingly unattainable in many public urban landscapes in England. These approaches could be integrated with the use of mulches (such as charcoal) applied in deeper layers to more effectively suppress weed germination from the underlying soil weed seed bank. We suggest that the crude, non-selective, but effective techniques borrowed from restoration ecology and nature conservation management for this study can contribute to more sustainable horticultural practices.

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