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Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production

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Comments

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RESEARCH

Evaluation of Grass and Legume Species as Perennial Ground Covers in Corn Production

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ABSTRACT

Corn (*Zea mays* L.) stover has been identified as an important feedstock for biofuel production but its removal will likely increase soil erosion. To address this issue 35 species of grasses and legumes were evaluated as potential perennial ground covers (PGCs) in corn. Selection of species encompassed both C3 and C4 species with a wide range of developmental and morphological features. The objectives were to (i) identify species that could support a high level of corn production while requiring minimal management and (ii) identify morphological traits and growth habits of suitable entries as PGC. Over the 3-yr study period species with slow growing and spreading habits were more conducive to corn production, even though these PGCs still caused an average 23% reduction in corn grain yield. Meadow fescue (*Festuca pratensis* Huds.), sheep fescue (*Festuca ovina* L.), Canada bluegrass (*Poa compressa* L.), fowl bluegrass (*Poa palustris* L.), and colonial bentgrass (*Agrostis capillaris* L.) were identified as suitable PGC species. These species were generally shorter and slower to spread into the corn rows compared with other, more aggressive species. Based on these observations an ideotype for future PGC species should be low growing, clump forming, and shade tolerant and have delayed green-up in the spring.

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Abbreviations: DAE, days after emergence; DM, dry matter; GDU, growing degree unit; HI, harvest index; NDVI, normalized difference vegetation index; PGC, perennial ground cover.

Estimates of world oil demand are projected to be as high as 18.4 million kL per day of oil equivalent by 2020 (National Research Council, 2009; IEA, 2010). This is nearly a 33% increase in relation to the demand experienced at the completion of this study. To reduce dependence on oil from both foreign and domestic sources, much attention has been given to cellulosic material as a feedstock for biofuel production. Corn stover could make up 30% of the estimated 500 million Mg dry material required by 2020. This assumes only a fraction of the material can be removed as stover residue is an integral part of soil conservation. The fraction removed could range from 0 to 40% depending on variability among production practices and topographical features used in corn production (Wilhelm et al., 2007; NASS, 2010). Other estimates indicate that 76 to 82% removal is possible if all production involved no-till practices (Glassner et al., 1999). Potentially, use of perennial ground covers (PGCs), sometimes referred to as living mulches, would allow for increased stover removal while preventing soil losses. Perennial ground covers can be defined as an annual or perennial plant that is interseeded with a row crop to confer an ecological, economical, or environmental benefit to the production system. Annuals are included in this definition as self-reseeding is intended for yearly reestablishment.

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Benefits of PGC include 96.7 to 100% reduction in soil erosion and 86.3 to 98% reduction in surface runoff (Hall et al., 1984), 67 to 99% reduction in runoff of pesticides such as cyanazine [2-(4-chloro-6-ethylamino-1,3,5-triazin-2-ylamino)-2-methylpropionitrile] and atrazine [1-chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine] (Rüttimann, 2001; Hall et al., 1984), 86% reduction in leached N (Liedgens et al., 2004), immobilization of N (Fageria et al., 2005), increased populations of predatory insects (Prasifka et al., 2006; Schmidt et al., 2007), and weed reductions (Enache and Ilnicki, 1990). Sometimes authors also include N contributions as a benefit when legumes are used as PGC but little evidence supports that desired levels of corn production can be achieved by N supplied by legumes (Sawyer et al., 2010; Zemenchik et al., 2000).

Historically PGCs have been associated with significant reductions in corn grain yields with unsuppressed ground covers generally performing the worst. Significant yield reductions ranging from 48 to 100% have been observed in species such as alfalfa (*Medicago sativa* L.), smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), and tall fescue (*Festuca arundinacea* Schreb.) under no-till conditions (Elkins et al., 1983; Eberlain et al., 1992). Reductions in corn grain yields when grown with PGC are sometimes linked to reductions in yield components and population. Populations have been reported to be reduced by 12 to 28% for Kura clover (*Trifolium ambiguum* M. Bieb.) and subterranean clover (*Trifolium subterraneum* L.) while harvest index (HI) has been reported to be reduced 61 to 89% in rainfed, no-tilled corn in alfalfa (Zemenchik et al., 2000; Eberlain et al., 1992). According to Zemenchik et al. (2000) cooler spring conditions may have played a role in the reduction of the corn population in Kura clover treatments through reduced germination. This is likely a good explanation as vegetative cover can affect soil temperatures (Monteith and Unsworth, 2008) and thus germination. Other factors that may affect establishment are reductions in soil thermal emittance, which may increase frost damage (Martin et al., 1999), and the competitive advantage that C3 species would have over corn during cool spring conditions.

Improvements in corn grain yield over no-till systems can be achieved with chemical and mechanical suppression of ground covers but results among studies are extremely variable as species, location, and management appear to interact. However, most studies that have evaluated rates of chemical suppression and tillage methods have observed production practices that would allow high levels of corn production. For instance, Hall et al. (1984) observed no difference between a conventionally tilled control and bird's-foot trefoil (*Lotus corniculatus* L.) when suppressed with paraquat (1,1'-dimethyl-4,4'-bipyridinium dichloride) and cyanazine. Elkins et al. (1983) observed similar success in tall fescue, orchardgrass, smooth bromegrass, and alfalfa but rates and chemicals involved with each species success sometimes varied. Strip-tillage is rarely used without chemical suppression but does appear to improve performance when used (Martin et al., 1999; Adams et al., 1970).

Resource availability undoubtedly plays a role in reducing grain yields when corn is grown with a PGC (Rajcan and Swanton, 2001). However, multiple studies indicated that shade avoidance may play a much larger role in constraining yield than previously credited (Page et al., 2009; Rajcan et al., 2004).

Most PGCs tested to date are the result of qualities believed to be important in minimizing competition with corn while achieving some ecological, economical, or environmental benefit. Little has been done to test the suitability of ground covers themselves in terms of their competitiveness, persistence, and cover provided. Therefore the objectives of this study are to (i) identify species that could support a high level of corn production while requiring minimal management and (ii) to identify characteristics of successful entries to enable an ideotype description.

MATERIALS AND METHODS

Field experiments were conducted at the Sorensen Research Station in Boone, IA (42°00′ N, 93°44′ W, 330 m asl), from 2008 to 2010. Plot soils consisted of predominately Clarion and Webster soils (0–5% slope, fine-loamy, mixed superactive, mesic Typic Endoaquolls) with Nicollet soils (0–3% slope, fine-loamy, mixed, superactive, mesic Aquic Hapludolls) and Canisteo soils (0–2% slope, fine-loamy, mixed, calcareous, mesic Typic Endoaquolls) making up a lesser portion (<5%). The field experiment was arranged as a split-block in time and consisted of three 1.4-ha blocks (replications), each of which were split into three landscape positions: summit (0–2%), slope (2–5%), and toeslope (0–2%). Thirty-five ground cover treatments (Table 1) and one bare soil control (subplots) were established perpendicular to the slope in 3-m wide strips from the toeslope to summit for a total of 108 treatments replicated three times over 3 yr. Perennial ground cover species were established in the spring of 2006 on tilled soil with a 2.1-m Tye 104-4404 Pasture Pleaser no-till seeder (AGCO Corporation) at 7.4 million pure live seed ha^{-1} (approx. 1.5 times the recommended rate for most species). Plots that did not establish well were tilled and reseeded or overseeded on 15 May and 4 June 2007 (Table 1). Plots that failed to establish during the May and June seedings were tilled and reseeded again on 15 Aug. 2007 with a Brillion SSP-5 seeder (Brillion Farm Equipment) to ensure good seed-to-soil contact, as this was believed to be the primary cause of poor establishment.

To establish corn in PGC plots, strip-tillage was used to create a cover-free zone for planting. Rows were established parallel to the slope and thus perpendicular to previously established groundcover treatments to create 36 3.0 by 23.0 m plots at each of the three landscape positions within the replication. Unfavorable weather conditions in the fall of 2007 and 2008 delayed strip-tillage until the following springs, but strips were tilled in the fall of 2009 for the 2010 growing season. Strip-tillage was

Table 1. Seeding dates and persistence of ground covers species grown in intrarow spaces of corn from 2006 through 2010.

Common name	Cultivar	Cover establishment†			Stand performance‡		
		15 Aug. 2006	23 May–4 June 2007	17 Aug. 2007	2008	2009	2010
Crested wheatgrass (*Agropyron cristatum*)	Highcrest	S	–	–	A	A	A
Colonial bentgrass (*Agrostis capillaris*)	Highland	S	R	–	A	A	A
Redtop (*Agrostis gigantea*)		S	R	R	A	A	A
Upland bentgrass (*Agrostis perennans*)		S	R	R	A	A	A
Creeping bentgrass (*Agrostis stolonifera*)	Seaside	S	R	R	A	A	NP
Creeping meadow foxtail (*Alopecurus arundinaceus*)	Garrison	S	–	R	A	A	A
Meadow foxtail (*Alopecurus pratensis*)		S	–	–	A	A	A
Sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.]	Butte	S	R	R	PE	NP	NP
Blue grama [*Bouteloua gracilis* (Kunth) Lag. ex Griffiths]		S	R	R	PE	NP	NP
Buffalograss [*Bouteloua dactyloides* (Nutt.) Columbus]		S	R	R	PE	NP	NP
Tufted hairgrass (*Deschampsia cespitosa*)		S	R	R	A	A	A
Canada wildrye (*Elymus canadensis*)		S	–	–	A	A	A
Riverbank wildrye (*Elymus riparius*)		S	–	–	A	A	A
Slender wheatgrass [*Elymus trachycaulus* (Link) Gould ex Shinners]		S	–	–	A	A	A
Virginia wildrye (*Elymus virginicus* L.)		S	–	–	PE	NP	NP
Weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees]		S	R	–	NP	NP	NP
Field fescue (*Festuca arvernensis* Auquier et al.)		S	R	R	PE	NP	NP
Hard fescue (*Festuca trachyphylla*)		S	O	–	A	A	A
Sheep fescue (*Festuca ovina*)		S	O	–	A	A	A
Red fescue (*Festuca rubra*)		S	O	–	A	A	A
Chewing's fescue [*Festuca rubra* L. subsp. *fallax* (Thuill.) Nyman]		S	O	–	A	A	A
Prairie Junegrass [*Koeleria macrantha* (Ledeb.) Schult.]		S	R	R	PE	NP	NP
Perennial ryegrass (*Lolium perenne*)	Spirit	S	O	–	A	NP	NP
Bird's-foot trefoil (*Lotus corniculatus*)	Norcen	S	R	–	A	NP	NP
Bulbous canarygrass (*Phalaris aquatica* L.)	Grasslands Maru	S	R	R	NP	NP	NP
Alpine bluegrass (*Poa alpina*)		S	O	R	A	NP	NP
Canada bluegrass (*Poa compressa*)		S	O	–	PE	A	A
Fowl bluegrass (*Poa palustris*)		S	O	R	A	A	A
Kentucky bluegrass (*Poa pratensis* L.)	Troy	S	O	R	A	A	A
Rough bluegrass (*Poa trivialis* L.)		S	O	R	PE	PE	NP
Tall fescue (*Festuca arundinacea* subsp. *arundinacea*)	Bulldog 51	S	O	–	A	A	A
Meadow fescue (*Festuca pratensis*)		S	R	R	A	A	A
Kura clover (*Trifolium ambiguum*)	Rhizo	S	R	–	PE	PE	PE
Crimson clover (*Trifolium incarnatum*)		S	R	–	NP	U	U
White clover (*Trifolium repens*)		S	R	R	A	NP	NP

†S = initial seeding; R = reseeded; O = overseeded.

‡A = acceptable (>50% cover); U = unacceptable (<50% cover); PE = poor establishment; NP = nonpersistent.

accomplished using a four-row Unverferth Ripper-Stripper (Unverferth Mfg. Co.) on 7 May 2008 and 4 May 2009, and for establishment of the 2010 crop, tillage was conducted 16 Nov. 2009. The Ripper-Stripper was customized with a single 0.44-m diam., 0.025-m fluted, 13-waved coulter in front followed by an adjustable deep-till shank that penetrated the soil to a depth of 0.25 m. Two sets of dual, offset coulters (identical to the front coulter) were mounted directly behind the shank and were adjusted in angle and width to accommodate a 0.30-m tillage width. A 0.38 m wide Rolling Harrow (Unverferth Mfg. Co.), 0.30 m in diameter, was attached behind the coulter to level and chop the seed bed. In 2008 and 2009, conventional tillage methods were used in the control plots but in 2010 only spring strip-tillage was conducted. Glyphosate [*N*-(phosphonomethyl) glycine], centered 0.30 m over the corn row, was applied at 3.0 kg a.i. ha^{-1} between corn growth stages V2 and V4 in an effort to suppress summer annual weeds. In 2010 additional grass and broadleaf control was banded with a tank mix of acetochlor [2-chloro-2'-methyl-6'-ethyl-N-ethoxymethylacetanilide], flumetsulam [N-(2,6-difluoropheny)-5-methyl-1,2,4-triazolo-[1,5a]- pyrimidine-2-sulfonamide], and clopyralid potassium salt (2,6-dichloro-anpyridinecarboxylic acid, potassium salt) at rates of 1.8, 0.05, and 0.14 kg a.i. ha^{-1}, respectively.

Field corn hybrid Pioneer 34A20 was planted in 0.76 m row spacings on 19 May 2008, 14 May 2009, and 21 Apr. 2010 with a four-row Kinze 3000 pull type planter (Kinze Mfg.). Populations in 2008 and 2009 were set at 80,000 seeds ha^{-1}, but calibration issues resulted in a population of 74,000 in 2010. Planting dates for 2008 and 2009 were later than recommended for Iowa (20 April–5 May [Elmore and Abendroth, 2001]) but rainfall events prevented earlier planting. Urea [$CO(NH_2)_2$] was applied at the equivalent of 168 kg ha^{-1} N in all 3 yr of the study. Phosphorus and K, in the forms P_2O_5 and K_2O, respectively, were applied based on yearly fall soil tests and soil fertility recommendations by Iowa State University Extension (Sawyer et al., 2002). To achieve "high" yearly levels of soil P and K the following rates were applied: 11 kg ha^{-1} P and 151 kg ha^{-1} K in 2008, 60 kg ha^{-1} P and 134 kg ha^{-1} K in 2009, and 50 kg ha^{-1} P and 134 kg ha^{-1} K in 2010. All soil amendments were band applied over the corn row at planting with a Gandy Model 62 Series air-delivery fertilizer system (Gandy Company). Soil pH ranged from 5.8 to 6.9.

Data Collection

Spring ground cover was determined at corn growth stage V4 in 2008 and 2009 and at V3 in 2010 based on the normalized difference vegetation index (NDVI), which was collected with a Crop Circle ACS-210 active sensor (Holland Scientific Inc.). The Crop Circle collects and georeferences red and near-infrared reflectance from the ground surface to allow the calculation and mapping of multiple vegetative indices. The sensor was mounted approximately 1.1 m from the soil surface on a custom, single bicycle wheel based platform to achieve a viewing width that corresponded to row width. Data points were collected at 5 Hz on alternating, interrow spaces (9 interrows per plot) and totaled approximately 90 to 100 NDVI data points per treatment. Georeferencing was accomplished using a Trimble AgGPS 432 (Trimble Navigation Limited) with real-time kinematic correction for accuracy and repeatability of less than 0.05 m. Normalized difference vegetation index was calibrated for estimating ground cover using georeferenced digital photos from within the mapped areas. One hundred eighty-four digital photos, sampled randomly and collected over 3 yr, were quantified for ground cover using a point analysis method based on 63 grid points. The percentage ground cover determined for each photo was regressed against the respective NDVI value at each photo location to produce an equation for estimating ground cover. The NDVI method of estimating ground cover could not be used in the fall as groundcovers were partially or completely senesced and had similar reflectance to bare or partially bare soil. Therefore, to collect fall ground cover data four random sample locations were chosen within each plot and a digital photo of interrow ground cover was taken. Ground cover for the strip-tillage band and the covered interrow space was individually calculated from each photo to give an estimate of total ground cover from cover species, corn residue cover, and ground cover encroachment into the strip-tillage area. The point analysis method was also used to quantify fall ground cover but due to the number of pictures (700–1000 yr^{-1}); only 25 grid points per photo were used.

Corn plant height data were collected at 2 to 3 wk intervals, as weather permitted, beginning at V6 and continuing until R1 for 2008 and 2010. Frequent rainfall events early in 2009 prevented initial height measurements until V9 but resumed at approximately the same interval and duration previously specified. Growth stage was determined based on the leaf collar method described by Abendroth et al. (2011). Ground cover heights were taken at the same time as corn height but maximum height for most species was achieved at or shortly after corn had reached V6. Mean plot heights were based on eight random height samples collected with a 3.0-m measuring stick. At harvest, grain and stover were collected from three random 1.16-m^2 samples for a total harvest area of 3.48 m^2 per plot. Corn stover was weighed in field and subsampled for moisture correction. Stover, grain, and cob samples were dried to a constant weight at 60°C and weighed to determine dry matter yield. A miscommunication during 2008 harvest resulted in the loss of cob data for that year.

Statistical Analysis

Yield, yield components, and ground cover data were analyzed as a repeated measures split-block in time with the PROC MIXED procedure in SAS (SAS Institute, 2004). All factors were considered fixed with the exception of block. Mean separation was conducted using the least significant difference method at the $\alpha = 0.05$ level (SAS Institute, 2004). Landscape position was analyzed as the whole plot with species as the subplot. Year was considered fixed due to the intrinsic interest of PGC persistence in years following establishment as well as its effect on corn. Regression analysis to determine the calibration equation for estimating ground cover from NDVI was developed using the PROC REG procedure in SAS. Correlations between variables such as corn height measurements, ground cover, cover height, and grain yield were conducted and tested for significance in R (R Development Core Team, 2009) using the Pearson product-moment correlation coefficient method (Pearson, 1896).

RESULTS

Weather

Sorensen Research Station on average receives 570 mm of precipitation and accumulates approximately 2900 growing degree units (GDUs) during an average growing season. Each of the three study years varied in terms of weather and also deviated from average conditions. In 2008 near average accumulation of GDUs (2779) were achieved from planting to harvest but rainfall totals of 720 mm, of which nearly 40% occurred between planting and 31 June, were problematic. Problems were further compounded by two hail storm events that occurred on 25 June and 29 July. The 2009 growing season was comparatively dry due to infrequent rainfall in June and August. Thus, plots accumulated only 440 mm of precipitation over the growing season. Temperatures were below average as well and resulted in approximately 360 fewer GDUs over the season. In 2010 record rainfalls produced 1090 mm of precipitation over the growing season with average temperatures producing 3077 GDUs. However, a frost event on 9 May 2010 severely damaged corn at growth stage V2 and delayed corn growth by 7 to 10 d. Leaf damage was not uniform across all treatments with controls showing less visible damage than PGC plots. Over the course of the study period many species failed to establish or did not persist from year to year. These species were not reseeded in following years as time constraints and poor weather conditions made reseeding difficult (Table 1). Therefore, species comparisons between years are not always possible.

Species had a significant effect on every variable collected yet it was also involved in two- and three-way interactions with landscape position and year among most variables. Due to these interactions, analysis was conducted and presented on a yearly basis.

2008 Growing Season

Species was the only significant effect on measured variables with the exception of corn height at 22 d after emergence (DAE), which also was affected by landscape position (data not shown). Grain yields among 2008 ground cover treatments were all significantly less than the control (Table 2). Alpine bluegrass (*Poa alpina* L.), white clover (*Trifolium repens* L.), bird's-foot trefoil, and tufted hairgrass [*Deschampsia cespitosa* (L.) P. Beauv.] were the highest yielding ground cover treatments in corn grain production but still reduced yields by 23 to 37%. It should be noted that these species did not persist beyond 2008, but treatments that yielded slightly less than these in 2008 were among the most successful in following years. Upland bentgrass [*Agrostis perennans* (Walter) Tuck.], redtop (*Agrostis gigantea* Roth), meadow foxtail (*Alopecurus pratensis* L.), and creeping meadow foxtail (*Alopecurus arundinaceus* Poir.) reduced yields from 77 to 89% and were the lowest yielding treatments in 2008. A comparison among the highest and lowest yielding treatments indicates little difference between species in terms of spring ground cover; however, the mature heights of ground covers among higher yielding treatments were usually shorter than the lower yielding treatments (data not shown). Total biomass results were similar to the results of grain yield production in terms to the significance between treatments (Table 2).

Harvest index, corn population, and ears per plant give some indication as to the source of yield reductions (Table 2). Meadow foxtail, redtop, and upland bentgrass treatments significantly reduced corn HI by 13 to 39% when compared to the control. Corn populations were reduced 16 to 30% as well among the four lowest yielding treatments. Several other species decreased corn population but the top ten yielding treatments did not significantly differ from the control. Upland bentgrass and redtop were the only two species that yielded significantly fewer ears per plant.

Spring ground cover among species varied between 54 and 82% total cover. In comparison with upland bentgrass, which produced 82% cover by corn growth stage V4, perennial ryegrass (*Lolium perenne* L.), crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.], hard fescue [*Festuca trachyphylla* (Hack.) Krajina (syn. *Festuca brevipila* R. Tracey)], meadow fescue, white clover, fowl bluegrass,

Table 2. Corn yield, yield components, and spring cover between perennial ground cover treatments for the 2008 growing season.

Species	Grain	Total biomass†	Harvest index†	Population	Ears per plant	Spring cover
	Mg DM‡ ha^{-1}	Mg DM ha^{-1}	no.	plants ha^{-1}	no.	%
Control	9.1	14.7	0.62	80,000	0.98	0
Alpine bluegrass	7.0	10.9	0.64	84,000	0.99	69
White clover	6.6	10.7	0.61	81,000	0.96	62
Bird's-foot trefoil	6.4	10.1	0.63	82,000	0.98	71
Tufted hairgrass	5.7	9.3	0.61	77,200	0.96	69
Perennial ryegrass	5.5	8.6	0.65	77,500	0.99	66
Kentucky bluegrass	5.0	7.9	0.63	74,800	0.95	72
Crested wheatgrass	4.7	7.5	0.62	72,000	1.00	64
Fowl bluegrass	4.4	7.1	0.61	81,600	0.96	62
Riverbank wildrye	4.3	6.8	0.62	77,100	0.98	54
Meadow fescue	3.8	6.4	0.59	80,000	0.99	63
Sheep fescue	3.5	5.9	0.58	67,300	0.96	60
Tall fescue	3.5	5.8	0.59	71,700	0.97	69
Red fescue	3.3	5.4	0.60	71,100	1.00	73
Creeping bentgrass	3.2	5.2	0.60	72,000	1.01	77
Chewing's fescue	3.1	4.9	0.63	63,200	0.98	72
Colonial bentgrass	3.1	5.2	0.59	71,900	0.97	79
Canada wildrye	3.1	5.2	0.59	74,600	0.95	72
Slender wheatgrass	3.0	4.8	0.61	69,200	0.93	69
Hard fescue	2.7	4.4	0.60	60,600	1.01	63
Creeping foxtail	2.1	3.8	0.57	67,300	0.91	73
Meadow foxtail	2.0	3.6	0.54	61,200	0.92	77
Redtop	1.1	2.8	0.38	59,900	0.76	79
Upland bentgrass	1.0	2.0	0.50	56,160	0.78	82
LSD (0.05)	1.4	2.2	0.07	10,300	0.10	15

†Cobs are not included in calculation.

‡DM, dry matter.

Table 3. Corn yield, yield components, and spring cover between perennial ground cover treatments for the 2009 growing season.

Species	Grain	Total biomass	Harvest index	Population	Ears per plant	Grain:cob
	Mg DM† ha^{-1}	Mg DM ha^{-1}	kg kg^{-1}	plants ha^{-1}	no.	kg kg^{-1}
Control	8.4	15.2	0.55	93,100	0.90	7.3
Meadow fescue	6.3	11.8	0.53	81,100	0.92	7.3
Colonial bentgrass	5.7	10.4	0.55	70,200	0.94	6.7
Tall fescue	5.0	9.3	0.53	68,500	0.94	6.9
Creeping bentgrass	5.0	9.2	0.53	73,300	0.89	7.0
Canada bluegrass	4.9	8.9	0.55	70,000	0.97	6.8
Sheep fescue	4.6	8.6	0.51	72,700	0.90	6.5
Fowl bluegrass	4.2	7.9	0.51	78,800	0.90	6.4
Tufted hairgrass	4.0	7.6	0.50	76,100	0.91	6.3
Hard fescue	3.9	7.2	0.52	67,600	0.90	6.6
Kentucky bluegrass	3.7	7.3	0.49	72,000	0.89	6.2
Chewing's fescue	3.4	6.7	0.50	68,500	0.86	6.1
Crested wheatgrass	3.0	5.9	0.49	64,700	0.83	5.5
Canada wildrye	2.7	5.2	0.50	67,300	0.79	6.2
Riverbank wildrye	2.6	5.4	0.45	61,000	0.77	5.8
Red fescue	2.6	4.8	0.50	63,800	0.80	5.8
Slender wheatgrass	2.2	4.2	0.48	63,800	0.80	5.3
Redtop	1.7	3.4	0.46	58,700	0.81	5.9
Upland bentgrass	1.6	3.3	0.43	58,000	0.81	5.4
Meadow foxtail	1.1	2.2	0.43	49,400	0.70	5.3
Creeping foxtail	0.7	1.9	0.23	42,700	0.42	3.6
LSD (0.05)	1.7	2.9	0.10	17,000	0.17	1.4

†DM, dry matter.

sheep fescue, and riverbank wildrye (*Elymus riparius* Wiegand) all provided less cover and ranged from 54 to 67%. All other species were nonsignificant in relation to the upland bentgrass.

Mature corn height followed the same trend as grain and total biomass yields with respect to ranking, with taller corn normally producing higher yields. At 22 DAE, when first corn height measurements were taken in 2008, the control was significantly shorter than most treatments. Of particular interest is that both short and tall ground cover species were among the treatments that showed significant height increases over the control. Ground cover height was positively correlated (r = 0.34) with corn height at 22 DAE but quickly deteriorated to a negative relationship (r = −0.36) by the end of the season. Spring ground cover showed no relationship (r = 0.02) with corn height at 22 DAE but did become negatively correlated (r = −0.43) with corn height by the last measurement date. By 42 DAE the control had become significantly taller than all other treatments. Based on the Pearson product-moment correlation coefficient method (Pearson, 1896) corn height and final grain yield had a strengthening positive linear relationship as corn approached maturity (data not shown). This relationship appeared to develop at or before 42 DAE.

2009 Growing Season

In 2009 species had a significant effect on all measured variables. A landscape position × species interaction was observed for grain yield and total biomass, with all effects being significant for spring cover (data not shown). As previously discussed, the 2009 growing season was relatively dry yet corn grown within colonial bentgrass, creeping bentgrass (*Agrostis stolonifera* L.), meadow fescue, sheep fescue, hard fescue, tall fescue, and Canada bluegrass produced significantly higher grain yields than any other year in which they were observed (Table 3). These species were also among the highest grain yielding treatments during the 2009 season but still reduced yields by 25 to 54% (Table 3). Hard fescue and sheep fescue increased grain yield from summit to toeslope approximately twofold (data not shown). Tall fescue treatments reduced corn yields 36 to 40% in the side-slope position in comparison with the summit and toeslope. Total biomass yields and grain yields followed that same basic trend but total biomass was more heavily influenced by stover material for creeping foxtail, meadow foxtail, and upland bentgrass as they had significantly lower HIs in comparison with the control.

Corn population in the control was well above that which was intended due to conventional tillage promoting volunteer corn. Therefore meadow fescue was chosen for making comparisons as the final population (81,100 plants ha^{-1}) was approximately equal to the intended population. Therefore, when compared to meadow fescue the seven lowest yielding treatments reduced populations by 25 to 47% while other treatments did not differ.

Many species that produced relatively thin cover in the spring were top in grain yield production and total

Table 4. Corn yield, yield components, and spring cover between perennial ground cover treatments for the 2010 growing season.

Species	Grain	Total biomass	Harvest index	Population	Ears per plant	Grain:cob
	Mg DM† ha^{-1}	Mg DM ha^{-1}	kg kg^{-1}	plants ha^{-1}	no.	kg kg^{-1}
Control	8.5	15.0	0.57	74,000	0.98	6.7
Canada bluegrass	3.4	6.0	0.57	65,400	0.84	5.8
Sheep fescue	3.2	5.7	0.57	59,300	0.89	5.8
Colonial bentgrass	3.2	6.2	0.52	62,700	0.79	5.4
Fowl bluegrass	3.2	5.7	0.53	60,200	0.82	5.5
Slender wheatgrass	3.1	5.4	0.55	59,300	0.77	5.8
Meadow fescue	3.1	5.7	0.55	53,900	0.82	6.0
Kentucky bluegrass	2.9	5.4	0.52	60,300	0.78	5.8
Hard fescue	2.8	5.0	0.56	60,900	0.80	5.7
Crested wheatgrass	2.7	4.9	0.54	52,200	0.89	5.2
Chewing's fescue	2.6	4.7	0.54	64,100	0.89	5.3
Tufted hairgrass	2.6	5.1	0.48	53,600	0.87	4.9
Canada wildrye	2.1	4.0	0.46	48,100	0.69	4.8
Riverbank wildrye	1.8	4.0	0.45	50,600	0.70	4.4
Upland bentgrass	1.7	3.7	0.46	56,700	0.68	4.8
Redtop	1.7	3.5	0.48	55,700	0.67	4.6
Tall fescue	1.5	3.3	0.43	47,300	0.66	4.4
Red fescue	1.5	3.0	0.50	55,500	0.70	4.9
Creeping foxtail	1.1	2.6	0.35	44,300	0.50	4.6
Meadow foxtail	0.8	2.1	0.37	47,800	0.65	3.7
LSD (0.05)	1.5	2.4	0.11	12,200	0.19	1.0

†DM, dry matter.

Table 5. Ground cover percentage among all grass species grown in corn during 2010. Data is categorized based on total spring and fall ground cover and on fall ground cover in the inter- and intrarow zones.

	Spring cover	Total fall cover (%)			Strip-tillage zone cover (%)			Interrow cover (%)		
Species	Species cover	Species cover	Corn residue	Bare soil	Species cover	Corn residue	Bare soil	Species cover	Corn residue	Bare soil
Chewing's fescue	76	75	21	4	54	38	8	89	9	2
Meadow foxtail	75	78	14	8	61	27	12	89	5	5
Red fescue	72	81	16	4	69	26	5	90	7	3
Upland bentgrass	69	76	17	9	61	29	10	87	8	5
Canada bluegrass	69	63	25	12	36	46	19	82	11	8
Tufted hairgrass	69	64	29	7	44	46	10	77	18	6
Redtop	69	70	19	11	55	30	15	80	12	9
Tall fescue	68	71	18	11	57	32	11	81	9	10
Creeping foxtail	68	76	16	8	65	26	9	83	10	7
Riverbank wildrye	68	58	29	13	36	46	18	73	18	9
Crested wheatgrass	68	47	35	18	32	45	23	57	29	14
Kentucky bluegrass	67	78	17	6	59	33	8	90	6	4
Canada wildrye	66	58	25	12	42	41	18	69	23	8
Colonial bentgrass	64	68	25	7	48	41	10	81	14	5
Slender wheatgrass	63	61	29	10	46	44	10	71	19	10
Hard fescue	62	76	19	5	59	34	7	88	9	4
Sheep fescue	59	71	21	7	52	38	10	84	11	6
Fowl bluegrass	57	66	24	9	46	38	15	79	15	5
Meadow fescue	53	48	28	23	32	41	26	60	19	19
Control	0	0	37	63	0	61	39	0	21	79
LSD (0.05)	10	13	9	6	17	13	8	12	10	5

biomass in 2009 and vice versa for dense cover producing species (Tables 4 and 5). For example, meadow fescue provided 54% cover, which was significantly lower than any treatment, yet it was also the highest grain yielding treatment among species (6.3 Mg grain dry matter [DM] ha^{-1}). Red fescue (*Festuca rubra* L.), meadow foxtail, Canada wildrye (*Elymus canadensis* L.), and riverbank wildrye produced 78 to 85% cover and were among the lowest corn grain producing treatments. Tall fescue did not follow this trend as it was one of the highest yielding (5.0 Mg

Table 6. Ground cover percentage among all grass species grown in corn during 2009. Data is categorized based on total spring and fall ground cover and on fall ground cover in the inter- and intrarow zones.

	Spring cover	Total fall cover (%)			Strip-tillage zone cover (%)			Interrow cover (%)		
Species	Species cover	Species cover	Corn residue	Bare soil	Species cover	Corn residue	Bare soil	Species cover	Corn residue	Bare soil
Red fescue	85	74	19	7	66	26	7	79	14	7
Meadow foxtail	81	82	9	9	71	16	13	89	5	6
Canada wildrye	78	65	19	16	51	27	22	75	14	12
Riverbank wildrye	78	60	24	16	50	32	18	67	23	15
Chewing's fescue	77	74	19	7	58	32	10	85	10	5
Tall fescue	77	62	23	15	45	35	20	74	15	11
Upland bentgrass	76	77	12	10	62	21	16	88	7	6
Redtop	75	70	17	13	55	26	19	80	11	9
Crested wheatgrass	75	55	25	19	41	35	23	64	19	17
Creeping foxtail	74	77	13	10	65	20	14	85	8	7
Slender wheatgrass	73	67	20	13	51	31	17	78	12	10
Kentucky bluegrass	73	68	22	10	50	36	13	81	12	8
Canada bluegrass	70	50	36	15	32	51	18	61	25	14
Sheep fescue	69	65	25	10	45	41	14	78	14	8
Tufted hairgrass	67	68	21	10	52	34	12	79	12	9
Fowl bluegrass	67	61	25	14	46	36	18	71	18	11
Colonial bentgrass	66	62	27	10	46	41	13	72	18	9
Creeping bentgrass	66	72	20	8	62	29	10	80	14	7
Hard fescue	65	73	19	8	56	34	10	84	10	6
Meadow fescue	54i	38	32	27	24	44	30	48	24	25
Control	0	0	–†	–	0	–	–	0	–	–
LSD (0.05)	8	13	11	5	14	13	7	14	9	6

†(–) indicates missing or nonapplicable data.

DM ha^{-1}) treatments as well as one of the higher spring ground cover producers (77%) in 2009. Correlations support the observation that a negative relationship (−0.51) exists between spring cover and grain yields.

Inferences on fall ground cover are difficult to make due to the presence of corn residue, yet when one considers the overlapping placement of corn stover and cover supplied by the treatments it appears that most species at the very least maintained similar ground cover to that measured in the spring (Table 6). It is most difficult to support this statement among species such as meadow fescue, tall fescue, and Canada bluegrass as the difference between spring and fall cover is substantial. However, it appears this statement is much more valid among other species, especially when increases in ground cover occur from spring to fall. Regardless, both spring and fall ground cover are significantly correlated (r = 0.63) and both show similar negative linear (−0.51 and −0.50, respectively) relationships with grain yield.

Initial corn height measurements taken 33 DAE were correlated (r = 0.56) with final grain yield and this relationship continued to strengthen over the season with taller plants being characteristic of higher yielding plots (data not shown).

2010 Growing Season

Early season frost in 2010 was extremely suppressive to grain yields. All C3 species continued to grow as corn seedlings recovered, giving them a competitive advantage early in the season. As a result, corn yields were reduced by 60 to 91% across all treatments (Table 4). Many of the same species that had done well in the previous years were still among the top yielding despite the adverse conditions created by the frost. The poorer yielding treatment from previous years also retained their rank among species in 2010. Tall fescue, which was very variable in its ranking over the study period, was one of the lowest yielding treatments in 2010. As in previous years, total biomass was similar in trend with grain yields but more species were associated with reductions in HI. Unlike 2008 and 2009, populations, ears per plant, and the grain:cob ratios all were associated with higher and lower yielding treatments rather than just the lower yielding treatments.

As in previous years, spring and fall ground cover were negatively associated with yield (Table 5). This is further supported by correlation coefficients of −0.39, −0.45, and 0.40 for the three respective measured variables. However, the relationship between spring and fall cover appears much weaker in comparison with 2009 (r = 0.33 vs. 0.63). Much is the same in 2010 in terms of the difficulties in interpreting and comparing fall ground cover with spring cover, but again cover was at least maintained over the season for most treatments.

Corn height measurements followed the same pattern as in the two previous growing seasons in which a positive linear relationship with grain yield was observed as measurements were taken at later dates in the season. Despite the later initiation of corn height measurements in 2010, evidence that shade avoidance occurred in corn was detected as measurements at 42 DAE were positively correlated with corn height ($r = 0.37$) yet slowly deteriorated and had become negative ($r = -0.15$) by the final corn height measurements.

DISCUSSION

Over the three growing seasons, meadow fescue, fowl bluegrass, and sheep fescue did consistently well relative to other species. If one considers 2009 and 2010 only, species such as colonial bentgrass and Canada bluegrass can be added to this list of recommended species. Given that a 0.30-m wide strip-tillage zone would at most allow for 60% cover in the spring, these species appear to maintain or increase cover over the growing season, also making them adequate PGC for this particular management system.

Of all the treatments evaluated, the species that were most successful with corn had slower vegetative spread rates and a relatively short stature at maturity. Considering the observation that delayed corn planting and frost decreased corn's ability to compete with ground cover species and that C3s are naturally more competitive in the spring, then delayed green-up in the spring could be added to the potential list of characteristics for an ideotype.

Weather patterns over the three growing seasons likely impacted the success of some PGC treatments through rainfall or temperature as control plot yields were not significantly different from year to year or between landscape positions within a growing season. Other factors that likely interfered with year-to-year success were strip tillage, which was more effective in suppressing intrarow cover in years following initial tillage, and the timing of corn planting as it may have given some advantage to the C3 species, especially if frost is a factor.

Slight differences in ground cover from season to season were observed among some species but did not always correspond to fluctuations in yield like that of cover height. However, spring cover was negatively correlated with final grain yield (−0.38 to −0.51). Species whose growth and development varied from year to year also happened to be among the highest yielding treatments from season to season. The variability in growth and development of these species is a fortuitous characteristic. Not only do they allow the highest corn yields but they also provided more flexibility in management under certain growing conditions. Other species that are relatively aggressive and fast growing would require a fast series of back-to-back events involving mechanical suppression, chemical suppression, and planting to maximize the length of time without competition.

Corn height measurements throughout the season give some indication that final grain yield is influenced by early season stressors. Given that soil fertility and water availability were in ample supply in early spring over the course of this study seems to support the idea that phenotypic constraints are a factor in yield reductions. As to the cause of this phenotype, this may relate to light quality issues from shading, poor quality of lateral reflected light (low red:far-red ratio), or a combination of both.

From observations collected over the 3-yr period, aggressive species or conditions that allow groundcovers to be more competitive may lead to reduced populations, lower HIs, fewer harvestable ears, and poor seed set. While ground cover increases can be beneficial for soil protection, spreading too fast can be a problem as well.

Although not quantified, observations of corn growth and development indicate that greater distances between PGC and corn plants produce healthier and taller plants. This was observed especially in 2008 when strip-tillage was first established and resulted in variability between neighboring corn plants. The cause of this phenomenon appeared to be due to uprooting of clump forming grasses, which created small zones that were wider than the strip-tilled width. Therefore, it appears that the proximity of a ground cover species to the row can heavily influence the growth and development of corn. Kumwenda et al. (1993) observed a similar response when varying the widths of a crimson clover (*Trifolium incarnatum* L.) PGC with chemical suppression. Other notable observations were striped and chlorotic leaves appearing shortly after emergence in PGC plot but not in the controls and obvious delays in tasseling in some PGC treatments.

CONCLUSIONS

Meadow fescue, fowl bluegrass, sheep fescue, colonial bentgrass, and Canada bluegrass performed well compared to other treatments. However, they still have the potential to significantly reduce corn yield in comparison to conventional cropping methods. This does not prevent their use in future experiments but instead promotes their use in studies where growth and development characteristics of a particular species may be used increase the success of other PGC production systems. Future systems could possibly include a combination of corn genetics tolerant to living ground covers and mechanical and chemical methods of PGC suppression.

Based on this study PGCs will require some type of suppression before corn planting to achieve competitive corn yields. Results indicate that a successful PGC would have the following characteristics: low growing, clump forming, and shade tolerant and have delayed green-up in the spring. Although not quantified one could also add characteristics such as summer dormancy and shallow rooting to minimize competition. These characteristics appear to support fundamental needs of corn concerning light quality, competition for resources, and to an extent the critical period of weed control. If these characteristics are not met with the correct ideotype, then intensity of suppression must be increased to prevent yield loss.

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