White Clover (*Trifolium repens*) Establishment within Dormant Bermudagrass Turf: Cultural Considerations, Establishment Timing, Seeding Rate, and Cool-season Companion Grass Species

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Abstract. White clover (*Trifolium repens* L.) inclusion is a proposed means of increasing the sustainability of certain low-maintenance turfgrass scenarios through increased pollinator habitat and as a result of the legume's ability to biologically fix atmospheric nitrogen (N). Proper white clover establishment is key to maximizing stand uniformity and N contribution to associated grasses. However, there are few guidelines for white clover establishment within warm-season turfgrasses. Four studies were conducted to evaluate seeded white clover establishment within a dormant hybrid bermudagrass [*Cynodon transvaalensis* Burt-Davy × *C. dactylon* (L.) Pers.] lawn as affected by 1) pre-seeding mechanical surface disruption; 2) establishment timing; 3) seeding rate; and 4) companion grass species. White clover establishment was improved by scalping before October seeding, but these effects were not further enhanced by the addition of verticutting or hollow tine aerification. Unscalped turfgrass yielded nearly 50% lower white clover densities than those scalped before seeding, possibly as a result of decreased seed-to-soil contact and increased bermudagrass competition. January and February establishment dates generally yielded the lowest spring clover densities, whereas October timing yielded superior establishment. Clover densities resulting from six seeding rates (0, 0.4, 0.8, 1.5, 3.0, and 6.0 g live seed/m²) were fit to the linear model ($y = y_0 + ax^b$, where y equals trifoliate leaves/m² and x is equal to initial seeding rate). An important feature of this model was that it accurately represented the diminishing response of increasing seeding rate. Clover establishment was negatively correlated with companion grass densities with the largest densities occurring when planted with tall fescue and the smallest when planted with annual ryegrass. Ultimately, scalping alone or in combination with other mechanical surface disruption should be paired with a clover variety acceptable to the height of cut and the environmental conditions of individual scenarios. Likewise, seeding rates and the decision to include a cool-season companion grass species will be dependent on the use of a turf and the desired green cover.

Benefits of turf are well documented and include: recreational health, erosion control, increased water infiltration, reduced nutrient leaching, aesthetics, carbon sequestration, and mediation of the “heat-island” effect (Beard and Green, 1994; Qian and Follett, 2002), yet the ecological impact of turf is often questioned, attributable in part to nutrient and water requirements (Milesi et al., 2005; Robbins et al., 2001; Robbins and Birkenholtz, 2003) as well as often-unustainable monoculture cultivation, which contributes to insect habitat

loss and fragmentation (Gels et al., 2002). For these reasons, the turfgrass industry is experiencing new demands for ecologically and economically sustainable maintenance options.

Inclusion of leguminous species, which biologically fixes N and provides a pollinator habitat (Abraham et al., 2010; Held and Potter, 2012; Rogers and Potter, 2004), is a proposed means of increasing the sustainability of certain low-maintenance turfgrass scenarios. However, little is known about inclusion of legumes in maintained turfgrass. Since the advent of herbicides, efforts in the turfgrass industry have often focused on maintaining monocultures for aesthetics and increased playability. Thus, a biologically diverse turfgrass sward with mixed species of grasses and broadleaf plants is sometimes

classified as weedy and therefore undesirable for scenarios such as golf courses and sports pitches. However, for many scenarios such as home lawns, roadsides, or other “unimproved” turfgrass areas, the environmental benefits of biodiversity may outweigh those of a monoculture.

White clover inclusion within maintained turfgrass has mainly been limited to cool-season turfgrass scenarios. Research by Sincik and Acikgoz (2007) reported increased color ratings in three cool-season turfgrass–white clover (*T. repens* L.) mixtures and that white clover fixed greater than 25 g N/m²/year and contributed between 4.2% and 13.7% of that total N to the associated turfgrass. Additional information concerning white clover inclusion within maintained turf is absent from peer-reviewed literature. However, information about the benefits of white clover inclusion within pasture systems is fairly abundant but mainly focused on perennial ryegrass (*Lolium perenne* L.)–white clover pastures. These mixed systems supply high-quality grazing for animals while simultaneously improving soil fertility (Lampkin, 2002). Estimates of N fixation for grass–white clover pastures range from nil to 40 g N/m²/year, although most are roughly 10 to 25 g N/m²/year (Ledgard and Steele, 1992; McNeill and Wood, 1990).

White clover is well suited for use within warm-season turfgrasses and is already a common feature within bermudagrass pastures of the southeastern United States (Brink and Fairbrother, 1991). Proper white clover establishment is key to maximizing stand uniformity as well as N contribution to associated grasses (Frame and Newbould, 1986). However, there are currently no guidelines for establishment within warm-season turfgrass scenarios common to the southeastern United States. Furthermore, unlike pasture systems, managed turfgrass scenarios may offer unique opportunities to manipulate turfgrass height and density as well as soil characteristics in favor of white clover establishment.

We hypothesized that white clover establishment is comparable to overseeding dormant warm-season turfgrass with cool-season grasses such as perennial ryegrass. However, unlike perennial ryegrass establishment rates (≈500 to 700 kg perennial ryegrass seed/ha), white clover establishment rates are much lower [Frame and Newbould (1986) recommend 3 to 5 kg white clover seed/ha].

There are several agronomic practices used to improve overseeded grass establishment within maintained turf scenarios. Scalping is among the most common techniques and refers to the excessive removal of living tissue at any one mowing occurrence (Turgeon, 2002). Although scalping often results in turfgrass injury, it is a means of exposing bare soil and eliminating turfgrass competition, which is essential to overseeded grass establishment. Verticutting, or vertical mowing, is another mechanical method often used to remove accumulated thatch or to elevate decumbent turfgrass before overseeding. Verticutting is performed by passing a rapidly rotating horizontal shaft with vertically oriented knives

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over affected turfgrass (Turgeon, 2002). Verticutting is often used in addition to scalping to prepare warm-season turfgrass for overseeding. Hollow tine aerification is less commonly used for fall overseeding but is an agronomic practice used to improve soil characteristics by removing cores of soil from turfgrass. Core sizes may vary, but the desired result is much the same. That is, the cores are removed to alleviate compaction by decreasing soil bulk density, accelerate drying, and increase infiltration of water and gasses. Once performed, cores are often collected or scattered, and the remaining holes are either filled with sand or left open (Turgeon, 2002).

Hypothetically, scalping alone or scalping in combination with verticutting and aerification may be a means of improving seeded white clover establishment through improved seed-to-soil contact and by limiting competition effects from associated turfgrasses. Soil aerification may also alleviate competition but has the added benefit of providing holes in which white clover may find more adequate soil conditions for initial establishment. It is therefore reasonable that it too should be tested as a means of improving white clover establishment.

Other variables that affect white clover establishment are establishment timing and seeding rate. Recommended establishment dates for white clover in the southeastern United States are largely anecdotal. For instance, establishment timing is often recommended from 2 to 6 weeks before historical first frost (1 Nov. in Auburn, AL). Previous research in Florida recommends September planting dates (Dudeck and Peacock, 1983), whereas others have recommended spring seeding to avoid hard freeze in more northern climates (Frame and Newbould, 1986). These dates are highly variable and dependent on locations and climate. Furthermore, they may not account for nuances of a maintained turf sward, which may insulate young white clover seedlings from effects of frost or hard freeze. Anecdotal to our own research, proper stand density is highly dependent on seeding rate, yet it does not appear to be a linear response, perhaps as a result of intraspecific competition.

White clover establishment within cool-season grass swards has largely been dictated by seed mixtures of cool-season grass blends containing creeping bentgrass (*Agrostis stolonifera* L.), kentucky bluegrass (*Poa pratensis* L.), or perennial ryegrass plus roughly 3% to 10% white clover by weight (Sincik and Acikgoz, 2007), yet these rates have not been evaluated in existing warm-season turf swards. Likewise, information about interaction effects of white clover and companion grass species is absent from the scientific literature. Alternative, grass-white clover mixtures for turfgrass are commercially available in much of Europe and the United States; however, they have not been evaluated for winter overseeding of dormant warm-season grasses.

Our objectives were to test the effects of pre-seeding mechanical surface disruption,

establishment timing, seeding rate, and companion grass species on establishment of two commercially available white clover populations within a dormant hybrid bermudagrass lawn. White clover was chosen as a model species for a variety of reasons, but specifically because turf-compatible white clover varieties are commercially available and as a result of white clover prevalence in maintained turfgrass as a weed species (Watschke et al., 1995). We present results that may influence future scientific studies and the use of white clover inclusion within warm-season turfgrass scenarios.

Materials and Methods

Studies were arranged as randomized complete blocks with four replications of various treatments described below. Studies were initiated 14 Oct. 2010 and 1 Oct. 2011 at the Auburn University Turfgrass Research Unit (lat. 32°34'40" N, long. 85°29'57" W; elevation 185 m) in Auburn, AL. Research was conducted within a maintained 'Tifway' hybrid bermudagrass [*Cynodon transvaalensis* Burt-Davy × *C. dactylon* (L.) Pers.] lawn on a Marvyn sandy loam (fine-loamy, kaolinitic, thermic Typic Kanhapludult) soil with an average pH of 6.3 (1:1 soil:H₂O). Turfgrass was maintained at a height of 3.8 cm with a rotary mower; all clippings were returned to the turfgrass surface. Plots received 3 cm supplemental irrigation on a weekly basis between March and September of 2011 and 2012. The area was fertilized with 5 g N/m² 15 Feb. 2011 and 20 Feb. 2012. Air temperature at a 1.5-m height, soil temperature at a 10-cm depth, and daily precipitation values were

obtained from a nearby weather station (lat. 32°36'00" N, long. 85°30'00" W; elevation 199 m) in Auburn, AL (AWIS, 2013; Fig. 1).

Four studies were conducted to evaluate the effects of pre-seeding mechanical surface disruption, establishment timing, seeding rate, and companion grass species on establishment of two commercially available white clover populations, Dutch White (Main Street Seed and Supply, Bay City, MI) and DLF Microclover (DLF-International Seeds, Halsey, OR). Seeds were drop-seeded through a stainless steel device, which contains five seed dispersion screens (6.4-mm² mesh openings) oriented horizontally to evenly scatter small grass and broadleaf seeds. With the exception of the seeding rate study, all clover was seeded at 1.5 g live seed/m². Trifoliate leaves were counted within three 730-cm² subsamples per 1.0-m² experimental unit on 20 Apr. 2011 and 2012 as a means of quantifying spring clover density (trifoliate leaves/m²). Companion grass plants were quantified using similar subsampling methods during January of 2011 and 2012 when bermudagrass was completely dormant.

Mechanical disruption study. This study evaluated common pre-overseeding cultural practices such as scalping, scalping plus verticutting, and scalping plus aerification and their ability to enhance seeded clover establishment relative to normally mown, non-scalped turfgrass. Treatments were arranged as a factorial to test the effects of four common cultural practices on the establishment of two commercially available clover populations. Treatments were intended to mechanically disrupt the soil surface as well as eliminate bermudagrass competition and

Fig. 1. Average daily air and soil temperature as well as average daily precipitation for the 2010–11 and 2011–12 bermudagrass-white clover growing seasons (AWIS, 2013).

included: scalping (6-mm mowing height), scalping plus verticutting (6 mm below soil level), and scalping plus hollow tine aerification (6-mm hollow tines; 3.8-cm depth; 15.2-cm spacing). Treatments also included a non-scalped control maintained at 3.8-cm mowing height. Clippings were removed from scalped surfaces, and clover was drop-seeded during October of each year.

Timing study. Treatments were arranged as a factorial to test the effects of seeding time (October through February) on establishment of two commercially available clover populations. Plots to be seeded were scalped at each seeding date, as previously described, and were blown free of clippings. Clover was seeded at monthly intervals beginning in October and ending in February.

Seeding rate. A seeding rate trial was arranged as a factorial to estimate the effects of seeding rate on establishment of two commercially available clover populations. Plots were scalped and blown free of clippings. Clover was seeded at 0, 0.4, 0.8, 1.5, 3.0, and 6.0 g live seed/m² in October of each year.

Companion grasses. Treatments were arranged as a factorial to test the effects of seeding companion grass species in combination with two commercially available clover populations. Companion species were: annual ryegrass (*Lolium multiflorum* Lam.), perennial ryegrass (*L. perenne* L.), creeping bentgrass (*Agrostis stolonifera* L.), red fescue (*Festuca rubra*), and rough stalk bluegrass (*Poa trivialis* L.; see Table 1 for rates and sources). Companion grasses and clover were seed-established in October of each year.

Statistical analysis. All data were subject to analysis of variance (ANOVA) within SAS procedure GLIMMIX using mixed model methodology (SAS[®] Institute Version 9.2, Cary, NC). Treatment was considered a fixed effect in the model. Year, replication (nested within year), and iterations containing these effects were considered random in the model (Carmer et al., 1989; Hager et al., 2003). Basic model assumptions were confirmed. Means were separated based on adjusted 95% confidence intervals, which allows for multiple comparisons by protecting family-wise error rate (Littell et al., 2006).

Least squares estimates for linear models were determined for rate-response studies using the Marquardt-Levenberg algorithm to provide the best fit (SPSS Inc., Sigma Plot Version 11.2, Chicago, IL). *R*² values were used to determine “goodness of fit” for the selected equations. Initial parameter ranges were selected with a maximum of 200 fits and 200 iterations. The relationship of clover density (trifoliate leaves/m²) to the clover seeding rates investigated in this trial was described using the linear model $y = y_0 + ax^b$, where *y* equals trifoliate leaves/m², *y*₀ equals the *y*-intercept (held constant at 0), *a* serves as a scaling factor (moving the values of *x*^{*b*} up or down), *x* is equal to initial seeding rate (g live seed/m²), and *b* is the scaling exponent that determines the function’s rate of growth or decay. A correlation between companion grass density and clover establishment was

described using Pearson product moment within SigmaPlot 11.2.

Results

ANOVA (Table 2) indicated that results for all studies differed as a result of replication year. For this reason, 2010–11 and 2011–12 (Seasons 1 and 2, respectively) results are presented separately for all studies. However, with few exceptions, treatment separations were similar across years and are used in support of our main conclusions. It is possible that the earlier initiation date of Season 2 (1 Oct. rather than 14 Oct.) affected clover establishment, because warmer air and soil temperatures (Fig. 1) led to delayed bermudagrass dormancy during Season 2 relative to Season 1.

Mechanical canopy disruption methods

Results were generally similar across seasons with scalping alone and in combination with other methods having enhanced spring white clover establishment (Table 3). When established in 2010, scalping alone and in combination with verticutting or aerification yielded 499, 502, and 513 trifoliate leaves/m², respectively. Normally maintained turfgrass (3.8-cm mowing height) yielded significantly lower white clover densities (279 trifoliate leaves/m²). Varietal differences were not detected during the Season 1 replication of this study.

Season 2 establishment densities were lower (*P* < 0.01) than those of Season 1 (Table 3). Scalping in combination with

aerification yielded higher spring establishment levels (204 trifoliate leaves/m²) than those of normally maintained turfgrass (six trifoliate leaves/m²) and scalping alone treatments (73 trifoliate leaves/m²). Scalping in combination with verticutting yielded 108 trifoliate leaves/m², which was greater than normally maintained turfgrass. Varietal differences were apparent during Season 2 with the Dutch variety having greater spring white clover density than Microclover (130 and 86 trifoliate leaves/m², respectively).

Establishment timing. During Season 1, October timing yielded superior spring white clover densities (199 trifoliate leaves/m²) relative to all other seeding dates (Table 4). November timing resulted in 68 trifoliate leaves/m², which was less than October timing but greater than the reduced stand densities of December, January, and February timings (22, 17, and four trifoliate leaves/m², respectively). Varietal differences were detected during Season 1 with the Dutch variety having yielded nearly double the white clover density of Microclover across establishment timings (80 vs. 44 trifoliate leaves/m², respectively).

Season 2 spring white clover establishment differed as a result of a timing-by-variety interaction (*P* = 0.0401). This interaction was largely the result of exaggerated varietal differences of the December timing, perhaps as a result of delayed seedling emergence of Microclover (data not shown). When established in December, the Dutch variety yielded 166 trifoliate leaves/m², whereas Microclover yielded only 50 trifoliate leaves/m². Similar trends were seen throughout the experiment;

Table 1. Companion grasses planted 14 Oct. 2010 and 1 Oct. 2011 with two commercial white clover varieties (1.5 g live seeds/m²).

Common name	Species	Variety	Rate (g·m ⁻²)
Perennial ryegrass	<i>Lolium perenne</i>	Top Gun II ²	20
Annual ryegrass	<i>Lolium multiflorum</i>	Marshall ³	30
Creeping bentgrass	<i>Agrostis stolonifera</i>	G-2 ⁴	10
Tall fescue	<i>Festuca arundinacea</i>	Rebel IV ⁵	30
Rough stalk bluegrass	<i>Poa trivialis</i>	Havana ²	50

²Jacklin Seed, Post Falls, ID.

³Wetsell Seed, Harrisonburg, VA.

⁴Tee-2-Green, Hubbard, OR.

⁵Pennington Seed, Madison, GA.

Table 2. Analysis of variance (ANOVA) for 2010–11 and 2011–12 white clover establishment trials.²

Study	Effect	F-value	P > F	F-value	P > F
		2010–11		2011–12	
Mechanical disruption study	Method	7.91	<0.0001	9.49	<0.0001
	Variety	3.30	0.0721	4.00	0.0495
	Method × variety	2.18	0.0766	0.66	0.6191
Establishment timing	Time	53.97	<0.0001	8.65	<0.0001
	Variety	15.77	0.0001	24.53	<0.0001
	Time × variety	1.60	0.1808	2.66	0.0401
Seeding rate	Rate	64.96	<0.0001	13.30	<0.0001
	Variety	2.59	0.1111	1.51	0.2227
	Rate × variety	2.16	0.0789	0.31	0.8735
Companion grass	Grass	32.37	<0.0001	7.85	<0.0001
	Variety	3.43	0.0670	0.01	0.9390
	Grass × variety	0.84	0.5043	0.62	0.6491

²Replication year was significant in all studies; therefore, analysis was performed separately. All data were subject to ANOVA within SAS procedure GLIMMIX using mixed model methodology. Treatment was considered a fixed effect in the model. Year, replication (nested within year), and iterations containing these effects were considered random in the model.

Table 3. April-observed spring white clover (*Trifolium repens*) density as affected by scalping and scalping in combination with mechanical surface disruption methods.

Season	Method	Trifoliate leaves/m ²	± 95% CI
2010–11	Scalp + aerification	513 a ^z	75
	Scalp + verticut	502 a	75
	Scalp alone	499 a	75
	Non-treated	279 b	77
2011–12	Scalp + aerification	204 A	49
	Scalp + verticut	108 AB	49
	Scalp alone	73 BC	49
	Non-treated	6 C	49

^zMeans were separated by 95% confidence intervals (CIs).

Table 4. White clover density as affected by seeded establishment timing.^z

Season	Time	Trifoliate leaves/m ²	± 95% CI
2010–11	October	199 a ^y	23
	November	68 b	20
	December	22 c	19
	January	17 c	19
	February	4 c	19
2011–12	October	51 BC	27
	November	91 AB	28
	December	108 A	27
	January	39 BC	27
	February	9 C	27

^yPlots to be seeded were scalped at each seeding date, as previously described, and were blown free of clippings.

^zMeans were separated by 95% confidence intervals (CIs).

however, no other establishment timing yielded significant varietal differences. These trends are again manifest by varietal main effects with the Dutch variety having yielded greater than double the white clover density of Microclover across establishment timings (90 vs. 29 trifoliate leaves/m², respectively).

Establishment timing main effects were again evident during Season 2 (Table 4). January and February timing clearly resulted in diminished spring white clover establishment levels with February timing having yielded only nine trifoliate leaves/m². However, unlike the previous season, October timing did not result in superior spring white clover densities (51 trifoliate leaves/m²). In fact, October timing resulted in spring white clover densities equal to that of November, January, and February timings (91, 39, and nine trifoliate leaves/m², respectively). December timing yielded the highest spring white clover density (108 trifoliate leaves/m²), which was equaled only by November establishment (91 trifoliate leaves/m²).

Seeding rate. April-observed white clover densities increased proportionally to October seeding rate (Fig. 2). For this reason, data were fit to the linear model $y = y_0 + ax^b$, where y equals trifoliate leaves/m² and x is equal to initial seeding rate (g live seed/m²). An important feature of this model is the diminished response of increasing seed yield. This characteristic highlights an important feature of white clover overseeding. That is, as white

clover-seeding rate increases beyond a certain point, competition effects may begin to reduce yield response. We acknowledge that these functions do not account for seasonable variability. There are many variables that presumably affect white clover establishment, including soil and air temperature as well as moisture availability.

Previous estimates of optimal clover density are lacking. Our own anecdotal evidence is that ≈100 trifoliate leaves/m² during the spring are aesthetically acceptable within a biodiverse turfgrass sward and do not limit bermudagrass green-up. Ideally, these equations could be used to estimate spring white clover densities and demonstrate the diminishing nature of seeded white clover yields. However, as a result of differences across years, it is difficult to predict seasonal outcomes of seeded establishment at any rate. In Seasons 1 and 2, 0.2 and 0.8 g live seed/m², respectively, would have achieved a suitable rate of 100 trifoliate leaves/m².

Companion grass study. Grass species affected spring white clover establishment during both seasons (Table 5). However, no differences resulting from white clover variety were observed. Season 1 spring white clover establishment was largest when seeded with tall fescue (383 trifoliate leaves/m²) and smallest when seeded with annual ryegrass (68 trifoliate leaves/m²). Creeping bentgrass yielded 262 trifoliate leaves/m², which was less than white clover density observed within tall fescue but greater than that of other companion grasses. Perennial ryegrass yielded 165 trifoliate leaves/m², which equaled the white clover density observed within rough stalk bluegrass (109 trifoliate leaves/m²) but was greater than that of annual ryegrass (68 trifoliate leaves/m²).

White clover establishment was generally lower during Season 2 (Table 5), but like the season prior, white clover establishment was largest when seeded with tall fescue (65 trifoliate leaves/m²). When seeded with creeping bentgrass, white clover density was 49 trifoliate leaves/m², which was similar to those of tall fescue and annual ryegrass (11

Fig. 2. April-observed white clover density as a function of five rates of October-seeded white clover. Error bars represent 95% confidence intervals about the mean.

trifoliate leaves/m²). Clover densities were lower than those of tall fescue and creeping bentgrass when seeded with rough stalk bluegrass and perennial ryegrass (seven and five trifoliate leaves/m², respectively) but equal to that of annual ryegrass.

Companion species were quantified during January of each season, whereas bermudagrass was dormant, because it was not possible to distinguish between the leaves of bermudagrass and companion species without introducing bias at other times of the year. During Seasons 1 and 2, spring white clover densities were negatively correlated with companion grass densities (Pearson correlation coefficients = -0.485 and -0.231, respectively; Fig. 3). Season 1 grass densities were inverse those of spring white clover with the highest grass density observed within rough stalk bluegrass (15,113 plants/m²). Annual ryegrass and perennial ryegrass densities (11,302 and 9,429 plants/m², respectively) were similar to one another but less than that of rough stalk bluegrass, whereas creeping bentgrass and tall fescue densities (3,810 and 2,647 plants/m², respectively) were lowest among companion grass species.

Season 2 grass densities were also inverse those of spring white clover densities with the highest grass density observed within rough stalk bluegrass (15,007 plants/m²; Fig. 3). Perennial ryegrass, annual ryegrass, and creeping bentgrass densities (8626, 8491, and 6264 plants/m², respectively) were less than that of rough stalk bluegrass but similar to one another, whereas tall fescue density (2454 plants/m²) was lowest among companion grass species.

Discussion

White clover spring seedling density was enhanced by scalping of the bermudagrass sward as well as scalping in combination with other mechanical surface disruption methods. White clover seed germination occurred 8 to 10 d after October seeding; however, white clover remained in the cotyledon stage for at least 1 to 2 weeks and was visibly more

Table 5. Companion grass densities along side affected white clover densities.

Yr	Grass	Trifoliolate leaves/m ²	± 95% CI	Grass plants/m ²	± 95% CI
2010–11	Tall fescue	383 a ^z	47	2648 c	1410
	Creeping bentgrass	262 b	42	3810 c	1410
	Perennial ryegrass	165 c	46	9429 b	1410
	Rough stalk bluegrass	109 cd	42	15113 a	1411
	Annual ryegrass	68 d	42	11302 b	1410
2011–12	Tall fescue	65 A	20	2454 C	1452
	Creeping bentgrass	49 AB	20	6465 B	1452
	Perennial ryegrass	11 BC	21	8491 B	1483
	Rough stalk bluegrass	7 C	20	15007 A	1516
	Annual ryegrass	5 C	20	8626 B	1483

^zMeans were separated by 95% confidence intervals (CIs).

Fig. 3. Correlation of December grass density and April white clover density during Seasons 1 and 2 of companion grass experiment, where r = Pearson's correlation coefficient and P = probability that r is different from 0. Correlations were only significant when white clover data were combined across companion grass species.

advanced in the growth stage when plots were scalped or when plants were grown on the fringe of unscalped plots. Long-term viability of mixed turf–white clover swards depends on proper establishment. Previous research confirms that the availability of photosynthetically active radiation is critically linked to N fixation (Chu and Robertson, 1974; Lie, 1971). Furthermore, reducing turfgrass height may increase the ability of white clover to avoid shade by increasing petiole length (Davies and Evans, 1990; Faurie et al., 1996; Woledge et al., 1992).

White clover seeding rate is undoubtedly important for proper establishment; however, recommendations for white clover seeding rates are scarce. Dudeck and Peacock (1983) recommended 1500 pure live seeds/m² be sown in September after verticutting Florida bermudagrass. However, these researchers did not report seed count per unit weight, as is often overlooked within overseeding studies. Logically, N contribution to associated grasses will be positively correlated with white clover density. However, too much white clover and the benefits of turfgrass may be voided (e.g., white clover may not withstand traffic or erosive forces as well as turfgrass). From our own research, as well as prior literature, we feel that 0.5 to 1.0 g·m⁻² is an appropriate white clover-seeding rate given available soil moisture and adequate time before first frost. However, seed counts per unit weight do differ with variety. For instance, in our own studies, Microclover contained 1209 seeds/g (± a SD of 21 seeds), whereas the Dutch variety contained 1510 seeds/g (± 24 seeds). These differences, although slight, do not explain all of the varietal differences observed

within our own research. An argument could be made that Microclover is a less aggressive white clover, unable to compete for light within a dense bermudagrass turf. Although undocumented, we also observed lower spring flower densities among the micro variety, which may decrease self-seeded propagation in following years.

Soil temperatures were not directly correlated with observed trends in establishment timing. Although inconclusive, it is clear that establishment-timing recommendations must be adapted to a wider range of warm-season turfgrass climates. Largely the best indicator within our own region is historical first frost, as a result of predictability and its timing with the onset of bermudagrass dormancy. Furthermore, existing turfgrass cover may be an important consideration when seeding white clover, because green turf cover may buffer surface temperatures as well as affect soil drying and seedling desiccation. Similarly, existing turfgrass may remain too dense if soil temperatures remain high. Like with any case of seeded establishment, proper agronomic principles should be used. That is, the decision must take into account forecast precipitation, cooling events, remaining turfgrass vigor, availability of supplemental water, and whether cultural methods may be used to disrupt or change any of these variables.

Warm-season turfgrass scenarios such as lawns and sports pitch are often overseeded with a cool-season alternative in the fall or early winter to enhance aesthetics and playability. This overseeding event offers a unique opportunity to simultaneously establish legumes. Cool-season legumes may contribute soil N for a sustainable overseeded sward as

well as for warm-season turfgrass breaking dormancy in the spring. Overseeding with a companion grass species may further the aesthetic value of mixed grass–white clover swards by providing year-round green turf and may help to better synchronize N mineralization and cycling for warm-season turfgrass demands. Intercropping with companion species is a means of capturing excess soil nutrients such as N and phosphorus, thus preventing them from entering ground and surface waters (Hauggaard-Nielsen et al., 2012; Martinez and Guiraud, 1990). Because cool- and warm-season grasses differ in growth cycles, an additional benefit of companion species may be that cool-season grasses act as a “catch crop” for fixed N, only to later contribute that N to the associated warm-season turf through decomposition of above- and below-ground plant parts.

Our research demonstrates cool-season turfgrass options and compatibility with white clover. However, future research must fully evaluate white clover-seeding rate by companion grass species interactions. The negative correlation of grass vs. white clover density detected within our own studies would be much better detected if companion grass seeding rates were treated as a planned treatment variable. Subsequent trials should evaluate the effects of winter grass cover on soil temperature and soil moisture, because both may vary with overseeded cover and subsequently affect white clover establishment. Future research should also evaluate N fixation and transfer to associated bermudagrass swards. Previous research has shown white clover inclusion to be a viable means of providing N to associated turfgrass. However, it is difficult to predict whether seeded white clover establishment of mixed turfgrass swards will be widely adopted by the turfgrass industry.

In summary, legume inclusion within warm-season turfgrass may play a role in sustaining low-maintenance scenarios such as lawns or roadside. However, legume inclusion offers unique challenges for turfgrass agronomists during seeded establishment.

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