

Rapid conversion of golf course turf to glyphosate-resistant creeping bentgrass

by

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DEDICATION

To God.

“For nothing will be impossible with God.”

-- Luke 1:37

“I can do all things through Christ who strengthens me.”

-- Philippians 4:13

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GENERAL INTRODUCTION

Generally, weeds are not a significant problem in golf course turf because of its competitive ability and the many herbicides available for selective removal. However, annual bluegrass (*Poa annua* L.) is able to colonize putting greens and fairways and populate major portions of these areas (Gaussoin and Branham, 1989). Annual bluegrass is susceptible to winterkill and is frequently compromised during hot and dry conditions (Beard, 1973). Its prolific seed production disrupts ball roll and destroys the aesthetics of putting greens and fairways (Lush, 1989). Annual bluegrass's capacity to produce many seeds results in a large seed bank and a constant source of new infestations (Beard, 1973). Selective removal of annual bluegrass that is consistently effective has not been achieved to date (Christians, 1996; Gardner et al., 2004).

Transgenic creeping bentgrass (*Agrostis stolonifera* L.) cultivars that are resistant to the herbicide glyphosate have recently been developed. Creeping bentgrass is the predominate turfgrass species grown on golf course putting greens in the temperate region of the U.S. Its use as a fairway turf has become more common because of its superior growth characteristics and playability (Fry and Butler, 1989; Reicher and Hardebeck, 2002). It has the capacity to withstand mowing at putting green or fairway height and forms a dense turfgrass stand ideal for the play of golf. Additionally, voids and divots in creeping bentgrass turf swards are quickly repaired because of its stoloniferous growth habit (Fagerness et al., 2000).

Establishment of golf course putting greens and fairways to glyphosate-resistant creeping bentgrass would likely improve weed control and ease overall management. Golf course superintendents could make more precise management decisions if they were able to maintain a monostand of creeping bentgrass rather than swards of both annual bluegrass and

the desired turf. Therefore, conversion of golf course turf to glyphosate-resistant creeping bentgrass is an option that many turfgrass managers may consider.

Traditional conversion methods begin by killing the existing turf with a nonselective herbicide (Reicher and Hardebeck, 2002). Core aeration with vertical mowing is commonly implemented to create gaps in the existing turf for seed placement, but in some situations, the dead sod is removed (Kendrick and Danneberger, 2002). In either case, establishment of creeping bentgrass in fairway turf takes at least 8 wk (Reicher and Hardebeck, 2002) and it is conceivable that putting green conversion could take much longer. Furthermore, weeds, especially annual bluegrass, can germinate after the nonselective herbicide is applied and the outcome of the conversion is a weed infested turf. To avoid this, seeding of conventional creeping bentgrass may be delayed so that an additional application of a nonselective herbicide can be made approximately 2 wk after the first. No matter what methods are used, the time needed for a complete conversion may not be acceptable to golf course club managers, members, and/or golfers.

Research conducted to speed the conversion of golf course turf to a different cultivar or species has focused on seeding into live-existing turf. In theory, the new cultivar or species would gradually out-compete the existing turf and become a major component of the turfgrass sward (Kendrick and Danneberger, 2002). Reicher and Hardebeck (2002) reported that if creeping bentgrass was overseeded several times into a perennial ryegrass (*Lolium perenne* L.) fairway, the complete establishment of creeping bentgrass might be possible, but it could take five or more years. Kendrick and Danneberger (2002) found that seeding creeping bentgrass into an established putting green was only successful when the existing creeping bentgrass was killed with glyphosate. It is apparent that competition from existing turf hampers the establishment of new seedlings.

The conversion of previously established turf to glyphosate-resistant creeping bentgrass is unique because glyphosate can be applied to remove weeds and competition from existing turf at anytime during the conversion process. Theoretically, glyphosate could be applied after seedlings have begun to establish and a gradual conversion to glyphosate-resistant creeping bentgrass would result. Golf could be played throughout the conversion with the exception of the time needed for seeding and time required to apply glyphosate.

Conversion of a previously established putting green to glyphosate-resistant creeping bentgrass proved to be unsuccessful in an experiment conducted at Iowa State University (Dant and Christians, 2005). In this study, seed was sown into core aerification holes and slits created by vertical mowing. Alternate equipment to prepare the surface for seeding is available to golf course managers. Large soil gaps created by core aerification decrease competition (Kendrick and Danneberger, 2002), but result in significant surface disruption. Furthermore, competition for existing turf can easily be removed by the application of glyphosate when converting turf to glyphosate-resistant creeping bentgrass. Therefore, surface preparation that results in smaller, more evenly distributed soil gaps may be more conducive to establishment.

Another method to improve turfgrass density and speed establishment is to increase the seeding rate. Kraft et al. (2004) reported greater success with higher-than-normal seeding rates in the renovation of a perennial ryegrass fairway to Kentucky bluegrass (*Poa pratensis* L.), but Reicher and Hardebeck (2002) found no advantage to increased rates of seed when converting a perennial ryegrass fairway to creeping bentgrass. Additionally, Madison (1966), and Rossi and Millett (1996) found that high seeding rates of creeping bentgrass result in immature seedlings that are susceptible to disease and death.

Disruption to golf play during conversion may not be acceptable. Consequently, major construction on golf courses in the Midwestern U.S. is conducted after Labor Day

(approximately September 1) to avoid interrupting a major portion of the season. However, low soil temperatures may decrease seed germination and seedlings may not fully develop before the winter season. Even when seed germination occurs, immature seedlings can die during harsh winter weather (Beard, 1973), resulting in unacceptable turf in the spring following conversion.

Research conducted at Iowa State University proved that conversion of putting greens to glyphosate-resistant creeping bentgrass could be successful if seeding occurred in the late summer (unpublished data, 2004). It was estimated that golf play could resume in early June. In this study, the putting green reached 100% turf cover in late-October, but the mowing height was not conducive for golf play. Mowing itself is a stress to turfgrass (Beard, 1973). The reduction in mowing height required to establish putting green turf increases the stress caused by mowing. Reduction in creeping bentgrass quality, root biomass and stress tolerance have been reported as mowing height decreases (Salaiz, et al., 1995; Fagerness et al., 2000; Fagerness and Yelverton, 2001). Conversely, tiller production and shoot density of creeping bentgrass, Kentucky bluegrass, and perennial ryegrass increase as the mowing height is moderately reduced (Krans and Beard, 1975; Lush and Rogers, 1992; Fagerness et al., 2000). This is also true regarding stolon production (Beard, 1973). Additionally, when glyphosate-resistant creeping bentgrass is mowed at higher initial heights, greater defoliation will result when the height of cut is reduced to levels required for golf play. Ideally, an equilibrium can be attained that causes minimal stress, while stimulating creeping bentgrass horizontal growth and shoot density.

The application of greater levels of N fertilizer is another approach utilized to speed establishment (Turner and Hummel, 1992; White, 2000). However, the positive effects N might have on establishment speed can have negative long-term effects. The incidence of Pythium blight (*Pythium ssp.*) increases with high N fertilization (White, 2000; Beard, 2002).

High N rates can decrease root production by causing excessive shoot growth (Beard, 1973). Additionally, N not used by the turfgrass plant may run off the site and/or leach through the soil profile. The negative effects of increasing N fertilization could negate any increase in speed of establishment.

This research was conducted to investigate the effect of the following factors on conversion of existing fairway and putting green turf to glyphosate-resistant creeping bentgrass: (i) timing of glyphosate application to remove competition from existing grasses, (ii) seeding date, (iii) glyphosate-resistant creeping bentgrass seeding rate, (iv) surface preparation method, (v) mowing practices after seedling germination, and (vi) N fertility.

Thesis Organization

This thesis is divided into five chapters. The first chapter describes the general scope of the research and why it was needed. Chapter two is a manuscript accepted by the *International Turfgrass Society Research Journal* describing field experiments conducted at Veenker Memorial Golf Course in Ames, IA. The third and fourth chapters describe field experiments conducted at the Iowa State University Research Station near Gilbert, IA and chapter five is a summary of the results and overall conclusions drawn from this research.

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**TIMING OF ROUNDUP[®] APPLICATION CRITICAL WHEN CONVERTING GOLF COURSE TURF TO
ROUNDUP READY[®] CREEPING BENTGRASS**

A paper accepted by the *International Turfgrass Society Research Journal*

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ADDITIONAL INDEX WORDS. conversion, genetically modified grass, glyphosate, overseeding.

Abstract

Roundup Ready[®] creeping bentgrass (*Agrostis stolonifera* L.) may provide a management tool to control annual bluegrass (*Poa annua* L.) infestation in putting greens and fairways. Unfortunately, conversion of existing golf course greens and fairways can take several months. The objective of this study was to determine the best timing for application of Roundup[®] [glyphosate, N-(phosphonomethyl)glycine] during conversion to Roundup Ready[®] creeping bentgrass to eliminate competition from conventional grasses. The study was conducted on an established 'Penncross' creeping bentgrass green and on fairway areas of perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass (*Poa pratensis* L.) and creeping bentgrass. One plot in each replication was stripped of sod and Roundup Ready[®] creeping bentgrass was seeded into bare soil. The remaining plots were core aerified, verticut, and overseeded. All areas were seeded on 3 Sept. 2002. Treatments included applications of glyphosate at 1.68 kg a.e. ha⁻¹ at intervals before and after seeding. The best timing of glyphosate application for fairway conversion was before seeding or shortly after

seeding. Applications timings later than 28 d after seeding resulted in competition from conventional turf, thereby increasing the time required to achieve full cover of Roundup[®] Ready creeping bentgrass. It was determined that fairway areas seeded in late summer could be converted successfully and be open to play early the following spring. Conversion of greens using these methods, however, would require that the area remain closed for several months after seeding, therefore additional research is being conducted at Iowa State University to develop other conversion methods for greens.

Abbreviations

RRCB: Roundup Ready[®] creeping bentgrass

Introduction

Roundup Ready[®] creeping bentgrass (RRCB) (*Agrostis Stolonifera* L.) is expected to be released for commercial use in the next few years. The use of a nonselective herbicide for weed removal, specifically annual bluegrass (*Poa annua* L.), could be valuable to golf course managers. To date, preemergence and postemergence herbicides and plant growth regulators have been shown to provide varying control of annual bluegrass in creeping bentgrass (Christians, 1996). Control with preemergence herbicides is difficult due to the existence of perennial biotypes of annual bluegrass and its ability to produce seed throughout the growing season (Christians, 2004). Although postemergence herbicides have been effective at reducing annual bluegrass populations, they are often phytotoxic to creeping bentgrass (Vargas and Turgeon, 2004). Plant growth regulators have been used to control seed production of annual bluegrass and reduce its vigor (Beard, 2002; Vargas and Turgeon, 2004). Plant growth regulators can reduce annual bluegrass populations, but rarely result in complete control (Christians, 1996). Many golf courses in the USA may want to convert

existing greens and fairways to RRCB to enhance weed management. However, some may be hesitant to renovate to RRCB because of lost revenue and the disruption to play the conversion process might cause.

Conventional conversion methods usually start with eradication of existing turf using a nonselective herbicide. Soil openings are created through aerification and vertical mowing or in some cases, the dead sod is removed. The seed is then applied to bare soil or in the gaps created in the dead turf. Nonselective herbicides cannot be applied to the area after seedlings begin to germinate with conventional creeping bentgrass. This conversion process could take several months before a putting green or fairway is in playable condition.

The renovation to RRCB is unique because glyphosate can be applied to the turf after the new glyphosate-resistant seedlings have emerged. This could reduce the time required for conversion. Additionally, golfers could potentially continue to play the course while the new seedlings are emerging.

The objective of this study was to determine the effect of glyphosate application timing on conversion of a creeping bentgrass green, and fairways of creeping bentgrass, Kentucky bluegrass (*Poa pratensis* L.), and perennial ryegrass (*Lolium perenne* L.) to RRCB and to investigate the impact of competition from conventional grasses on the establishment of RRCB.

Materials and Methods

The study was conducted at Veenker Memorial Golf Course in Ames, IA on an area established for research. It was located in a flood plain and the soil type was a Coland clay loam (fine loamy mixed mesic Cumulic Haplaquoll) with a pH of 7.7, 6.1% organic matter, 51 ppm P, and 122 ppm K. The research area was constructed with native soil but the soil had been disturbed before the area was created. The study was a randomized complete block design. All plots were 1.5 x 1.5 m with treatments replicated three times. The green was

100% 'Penncross' creeping bentgrass. The fairways consisted of either 100% 'Trueline' creeping bentgrass, 100% Scotts 100-81600 perennial ryegrass blend (36% 'Divine', 33% 'Majesty', 30% 'Enchanted' by seed weight), or a Double Eagle Kentucky bluegrass blend (30% 'Apollo', 25% 'Serene', 15% 'Conventry', 15% 'Envicta', 15% 'Blackstone' by seed weight) interspersed with 'Penncross' creeping bentgrass.

Putting Green Study

The study was initiated on 17 Aug. 2002 and continued into the 2003 season. One plot in each replication was treated on 17 August with glyphosate at 1.68 kg a.e. ha⁻¹ diluted to a total spray volume of 1222 L ha⁻¹. All grass and thatch was removed on 1 Sept. 2002 and the plot was prepared as a seedbed. This was the bare-soil treatment. All other glyphosate treatments took place as described in Table 1 at a rate of 1.68 kg a.e. ha⁻¹, with the exception of the split-application treatment in which glyphosate was applied four times at 0.42 kg a.e. ha⁻¹. During seed production, only 50% of the seed is Roundup Ready[®] and the other 50% is conventional creeping bentgrass (E. Nelson, personal communication, 2002). Therefore a glyphosate application was made 28 d after seeding to remove glyphosate-susceptible seedlings. As explained in Table 1, this treatment was only applied to some plots.

Before initiation and while the study was being conducted, the experimental area was mowed on a daily basis at 3.8 mm. Clippings were collected and removed from the site. The area was core aerified in two directions on 3 Sept. 2002 using a Ryan GA-30 (Jacobsen, A Textron Company, Charlotte, NC) equipped with 1.6-cm diam. by 7.6-cm long hollow-tines. The aerification depth was 5 cm. Tine spacing was 6.4 cm between rows and 5 cm within rows. Cores were removed and aerification holes were filled by topdressing with 4 mm of silica sand. A Toro Greensmaster 3100 (The Toro Company, Bloomington, MN) with

verticutting units set to cut 3 mm into the soil, was used to create slits for seed placement. Roundup Ready[®] creeping bentgrass seeding took place using a drop spreader at a rate of 85 kg ha⁻¹ of 50% RRCB seed, 50% conventional creeping bentgrass seed supplied by the O.M. Scotts Company (Marysville, Ohio). The area was again vertically mowed to promote seed-to-soil contact. A 14-12.3-8.3 (N-P-K) starter fertilizer was applied to the area with N at 56 kg ha⁻¹, P at 49 kg ha⁻¹, and K at 33 kg ha⁻¹. Daily irrigation was applied to promote seed germination.

Fairway Studies

All glyphosate application rates and application dates were identical to those stated in the putting green study. The bare-soil plots were treated with glyphosate on 17 Aug. 2002 and the dead sod was removed on 1 Sept. 2002 to prepare a seedbed. The area was mowed at 1.5 cm before the study began and throughout its duration. Clippings were allowed to fall on the plot area. On 3 Sept. 2002, core aeration of the plots occurred in the same manner as stated above. The cores were broken up using a Toro triplex Greensmaster 3100 equipped with verticutting units set to penetrate into the soil 1.5 mm. The plots were dragged to disperse aeration cores and debris was removed with backpack blowers. Seed was applied as stated previously and the area was again vertically mowed. A starter fertilizer was applied as stated in the putting green procedure. The area was irrigated daily to promote seed germination.

Any remaining glyphosate-susceptible turf was removed on 7 May 2003 by applying glyphosate at 1.68 kg a.e. ha⁻¹ to the putting green study and fairway studies. Applications to all studies of 37 kg ha⁻¹ N, 8 kg ha⁻¹ P, and 76 kg ha⁻¹ K using a 10-2.2-20.8 (N-P-K) fertilizer were made on 15 May and 29 May 2003.

Data Collection and Analysis

Acceptable turfgrass cover (both RRCB and the existing turfgrass species) was recorded on 12 Oct., 25 Oct., and 1 Nov. 2002. In the spring and summer of 2003, acceptable turfgrass cover was recorded on the following dates: 7 May, 1 June, 23 June, and 17 July. The percentage cover was estimated by visual observation of the whole plot. Data were analyzed in SAS (SAS Institute, 1999-2001) using ANOVA with mean separation determined by Fisher's protected LSD.

Results and Discussion

Putting Green Study

None of the application timings resulted in adequate RRCB cover to allow the converted green to be deemed playable by the spring of 2003. The bare soil plots had 75% cover on 7 May 2003 (Table 2). This increased to 94% by 17 July, but this was still not acceptable for play. Plots that were not treated with glyphosate until 7 May 2003 had 100% cover of acceptable turf on this date. However, this was a combination of RRCB and conventional creeping bentgrass. On 1 June, following the 7 May glyphosate treatment, the cover decreased to 4%. Conventional bentgrasses were highly competitive with RRCB and the conventional bentgrasses should be removed early in the establishment process.

The most effective glyphosate application timing was 7 d before seeding (Table 2). As the time from seeding to glyphosate treatment increased, RRCB cover decreased because of competition from conventional creeping bentgrass. The removal of existing turf early in the conversion process resulted in greater RRCB establishment.

Fairway Studies

On 7 May 2003, RRCB cover on the creeping bentgrass fairway was the same as the bare soil plots when applications of glyphosate were made 7 d before seeding, at seeding and 7 d after seeding (Table 3). This was also true on 1 June. By 17 July, turf cover was 100% on all plots except those that were treated only in the spring of 2003.

Glyphosate applications taking place 7 d before seeding, at the time of seeding, and 7 and 14 d after seeding were most effective in the conversion of the existing Kentucky bluegrass fairway to RRCB. Turf cover of the plots were not different when compared to the bare soil plots on 7 May (Table 4). By 1 June, the later treatment timings began to approach the same RRCB cover as the earlier glyphosate treatments.

On the perennial ryegrass fairway, like the other trials, RRCB conversion was most successful when glyphosate applications were made close to the time of seeding. Applications of glyphosate made 7 d before seeding, at the time of seeding, and 7 d after seeding resulted in the same RRCB cover as the bare soil plots on 7 May 2003 (Table 5). By 1 June, plots treated with glyphosate 7, 14, and 28 d after seeding had turf cover had increased considerably. Turf cover of the application timings 7 d before seeding, at seeding, and 7, 14, and 28 d after seeding were equivalent.

Similar to the putting green trial, competition from the existing turfgrass species was significant in all fairway trials. Plots receiving glyphosate for the first time in the following spring had 7, 5, and 30% RRCB cover for the creeping bentgrass, Kentucky bluegrass, and perennial ryegrass fairways on 1 June 2003, respectively. In contrast, RRCB coverage was 99% on the same date for all fairway plots to which glyphosate was applied 7 d before seeding.

It appeared that the perennial ryegrass was less competitive than Kentucky bluegrass and creeping bentgrass maintained at fairway height. Turf cover on 7 May 2003 of plots

receiving glyphosate applications 28 d after seeding was 72% on the perennial ryegrass fairway compared with 55 and 60% on the creeping bentgrass and Kentucky bluegrass fairways, respectively. This trend was also apparent on plots treated only in the spring following seeding. On 1 June, RRCB cover of these plots was 30, 5, and 7% on the perennial ryegrass, creeping bentgrass, and Kentucky bluegrass fairways. Perhaps these differences are a result of the rhizomes of Kentucky bluegrass and stolons of creeping bentgrass. The bunch type growth habit of perennial ryegrass may be less competitive to newly establishing RRCB seedlings.

Competition from the existing turfgrass and from conventional creeping bentgrass included in the RRCB seed was evident. Consequently, the earlier the competition is removed, the more successful the establishment of RRCB will be. Similar observations have been made during the establishment of conventional creeping bentgrass. In an annual bluegrass/creeping bentgrass fairway, the population of creeping bentgrass was increased only 8% by overseeding with creeping bentgrass over 3 yr (Gaussoin and Branham, 1989). Reicher and Hardebeck (2002) found that conversion of a perennial ryegrass fairway to creeping bentgrass may be possible, but estimated that the complete establishment of creeping bentgrass could take five or more years and require multiple overseeding events. We observed that when RRCB overseeding occurs late in the summer and competition from the existing fairway turf is removed shortly after seeding, conditions can be suitable for play early the following spring.

Similar to results reported by Kendrick and Danneberger (2002), we observed that when seeding into a putting green, many of the aerification holes were occupied by seedlings in the period shortly after seeding. However, as the study progressed many of these new seedlings apparently died. Kendrick and Danneberger (2002) showed that intraseeding into existing putting greens is not successful, citing that death of new seedlings is likely due to

root competition from the existing turfgrass. Snaydon and Howe (1986) seeded annual bluegrass, rough bluegrass (*Poa trivialis* L.), and creeping red fescue (*Festuca rubra* L.) into established perennial ryegrass and studied shoot and root competition between the established turf and seedlings. They also reported that seedling growth was limited due to root competition. Cattani (2001) examined the vigor of seedlings emerging from aerification holes and reported that competition from live turf reduced tillers plant⁻¹ by 90% and dry weight plant⁻¹ by 95% when compared to dead turf. In our study, even when competition was removed early, conversion to RRCB was still not satisfactory for the putting green.

The fertilizer program used in this study was based on the site and soil characteristics. Turfgrass cover might have been increased if a more rigorous fertilizer regime was used and frequent topdressing occurred. Beard (2002) recommends 15 to 29 kg ha⁻¹ N on 7-to 10-d application intervals and weekly topdressing 6-to 8-wk following seeding. However, increasing vigor through fertilization could increase the competition from existing turf, negatively impacting the survival of seedlings. In addition, during the entire duration of the study the mowing height was maintained at 3.8 mm. Although maintaining turf at lower mowing heights may remove aboveground competition for light, Cattani (2001) suggested that greater mowing heights might improve seedling survival. At Iowa State University we are currently conducting research to study the effects of fertilizer and mowing practices on conversion of existing putting greens to RRCB.

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Table 1. Experimental treatments and the date each glyphosate application was made to investigate the effects of glyphosate timing before and after seeding on establishment of Roundup Ready® creeping bentgrass.

Glyphosate application timing	Date of application				
	First	Second	Third	Forth	Final
14 d before seeding, remove sod and prepare seedbed; treat again 28 d after seeding	17 Aug. 2002	1 Oct. 2002	----	----	7 May 2003
7 d before seeding and 28 d after seeding	23 Aug. 2002	1 Oct. 2002	----	----	7 May 2003
Time of seeding and 28 d after seeding	2 Sept. 2002	1 Oct. 2002	----	----	7 May 2003
7 d after seeding	9 Sept. 2002	----	----	----	7 May 2003
7 and 28 d after seeding	9 Sept. 2002	1 Oct. 2002	----	----	7 May 2003
14 d after seeding	17 Sept. 2002	----	----	----	7 May 2003
14 and 28 d after seeding	17 Sept. 2002	1 Oct. 2002	----	----	7 May 2003
28 d after seeding	1 Oct. 2002	----	----	----	7 May 2003
At seedling emergence at 0.42 kg a.e. ha ⁻¹ ; apply three repeated applications at 0.42 kg a.e. ha ⁻¹ at 2-wk intervals	9 Sept. 2002	17 Sept. 2002	1 Oct. 2002	28 Oct. 2002	7 May 2003
The end of the 2002 growing season	1 Nov. 2002	----	----	----	7 May 2003
No glyphosate application until the spring of 2003	----	----	----	----	7 May 2003

Table 2. Percentage cover of Roundup Ready[®] creeping bentgrass on an area previously established to ‘Penncross’ creeping bentgrass maintained at putting green height. The area was seeded with Roundup Ready[®] creeping bentgrass on 3 Sept. 2002. Values are means of observations from three replications.

Glyphosate application timing	Date						
	2002			2003			
	12 Oct.	25 Oct.	1 Nov.	7 May	1 June	23 June	17 July
	%						
14 d before seeding, remove sod and prepare seedbed; treat again 28 d after seeding	50 b [†]	70 b	78 b	75 b	83 a	88 a	94 a
7 d before seeding and 28 d after seeding	38 de	45 c	58 c	52 c	75 a	82 a	90 ab
Time of seeding and 28 d after seeding	27 fg	40 cd	45 cde	40 d	60 b	67 b	80 bc
7 d after seeding	32 ef	45 c	48 cd	35 de	48 bcd	67 b	83 bc
7 and 28 d after seeding	22 fgh	32 cd	35 def	28 ef	55 bc	60 bc	73 cde
14 d after seeding	17 gh	27 de	32 efg	32 de	43 cde	48 cd	77 cd
14 and 28 d after seeding	12 h	14 e	22 fgh	17 g	40 de	52 c	65 e
28 d after seeding	47 cd	28 de	12 h	25 efg	32 ef	48 cd	73 cde
At seedling emergence at 0.42 kg a.e. ha ⁻¹ ; apply three repeated applications at 0.42 kg a.e. ha ⁻¹ at 2-wk intervals	78 b	47 c	20 gh	18 fg	42 de	52 c	73 cde
The end of the 2002 growing season	100 [‡] a	100 [‡] a	100 [‡] a	4 h	20 f	37 d	53 f
No glyphosate application until the spring of 2003	100 [‡] a	100 [‡] a	100 [‡] a	100 [‡] a	4 g	20 e	67 de
LSD (0.05)	10	15	13	10	13	13	10

[†] Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher’s least significant difference test.

[‡] Values are percentages of a combination of Roundup Ready[®] creeping bentgrass and conventional turfgrass species.

Table 3. Percentage cover of Roundup Ready® creeping bentgrass on an area previously established to ‘Trueline’ creeping bentgrass maintained at fairway height. The area was seeded with Roundup Ready® creeping bentgrass on 3 Sept. 2002. Values are means of observations from three replications.

Glyphosate application timing	Date						
	2002			2003			
	12 Oct.	25 Oct.	1 Nov.	7 May	1 June	23 June	17 July
	%						
14 d before seeding, remove sod and prepare seedbed; treat again 28 d after seeding	43 d [†]	62 c	70 c	80 bc	96 ab	100 a	100 a
7 d before seeding and 28 d after seeding	73 b	85 b	83 b	90 ab	99 a	100 a	100 a
Time of seeding and 28 d after seeding	42 d	67 c	65 c	72 cde	90 abc	98 a	100 a
7 d after seeding	42 d	58 cd	63 cd	73 cde	87 bc	95 a	100 a
7 and 28 d after seeding	50 cd	60 cd	65 c	73 cde	85 c	98 a	100 a
14 d after seeding	23 e	47 ed	53 de	62 ef	70 d	88 bc	100 a
14 and 28 d after seeding	27 e	42 ef	48 e	67 def	83 c	93 abc	100 a
28 d after seeding	23 e	30 f	25 f	55 fg	72 d	85 c	100 a
At seedling emergence at 0.42 kg a.e. ha ⁻¹ ; apply three repeated applications at 0.42 kg a.e. ha ⁻¹ at 2-wk intervals	60 c	68 c	65 c	77 cd	83 c	93 abc	100 a
The end of the 2002 growing season	100 [‡] a	100 [‡] a	100 [‡] a	47 g	67 d	85 c	100 a
No glyphosate application until the spring of 2003	100 [‡] a	100 [‡] a	100 [‡] a	100 [‡] a	7 d	42 d	82 b
LSD (0.05)	11	14	11	12	11	9	3

[†] Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher’s least significant difference test.

[‡] Values are percentages of a combination of Roundup Ready® creeping bentgrass and conventional turfgrass species.

Table 4. Percentage cover of Roundup Ready[®] creeping bentgrass on an area previously established to Kentucky bluegrass maintained at fairway height. The area was seeded with Roundup Ready[®] creeping bentgrass on 3 Sept. 2002. Values are means of observations from three replications.

Glyphosate application timing	Date						
	2002			2003			
	12 Oct.	25 Oct.	1 Nov.	7 May	1 June	23 June	17 July
	%						
14 d before seeding, remove sod and prepare seedbed; treat again 28 d after seeding	55 c [†]	72 b	77 bc	88 bc	97 abc	100 a	100 a
7 d before seeding and 28 d after seeding	72 bc	82 b	80 bc	95 ab	99 a	100 a	100 a
Time of seeding and 28 d after seeding	78 b	82 b	87 ab	92 abc	100 a	100 a	100 a
7 d after seeding	68 bc	83 b	82 b	90 bc	94 abc	95 a	100 a
7 and 28 d after seeding	67 bc	77 b	77 bc	90 bc	98 ab	97 a	100 a
14 d after seeding	25 d	35 c	52 d	83 c	85 cd	95 a	100 a
14 and 28 d after seeding	33 d	43 c	52 d	73 d	86 bcd	95 a	100 a
28 d after seeding	27 d	22 d	10 e	60 e	77 de	90 a	100 a
At seedling emergence at 0.42 kg a.e. ha ⁻¹ ; apply three repeated applications at 0.42 kg a.e. ha ⁻¹ at 2-wk intervals	67 bc	72 b	67 c	90 bc	98 ab	100 a	100 a
The end of the 2002 growing season	100 [‡] a	100 [‡] a	100 [‡] a	45 f	67 e	92 a	100 a
No glyphosate application until the spring of 2003	100 [‡] a	100 [‡] a	100 [‡] a	100 [‡] a	5 f	52 b	88 b
LSD (0.05)	21	13	14	9	12	11	4

[†] Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's least significant difference test.

[‡] Values are percentages of a combination of Roundup Ready[®] creeping bentgrass and conventional turfgrass species

Table 5. Percentage cover of Roundup Ready® creeping bentgrass on an area previously established to perennial ryegrass maintained at fairway height. The area was seeded with Roundup Ready® creeping bentgrass on 3 Sept. 2002. Values are means of observations from three replications.

Glyphosate application timing	Date						
	2002			2003			
	12 Oct.	25 Oct.	1 Nov.	7 May	1 June	23 June	17 July
	%						
14 d before seeding, remove sod and prepare seedbed; treat again 28 d after seeding	60 bc [†]	68 c	70 cd	87 bc	100 a	95 ab	100 a
7 d before seeding and 28 d after seeding	80 ab	85 ab	90 ab	92 b	99 a	100 a	100 a
Time of seeding and 28 d after seeding	57 cd	72 bc	77 bc	85 bc	98 ab	100 a	100 a
7 d after seeding	38 cde	63 cd	72 cd	80 cde	95 abcd	98 a	100 a
7 and 28 d after seeding	35 de	60 cde	58 de	72 f	89 d	97 ab	100 a
14 d after seeding	17 ef	47 e	43 f	77 def	93 abcd	97 ab	100 a
14 and 28 d after seeding	28 ef	50 de	48 ef	75 ef	90 cd	97 ab	100 a
28 d after seeding	12 f	15 f	15 e	72 f	92 bcd	97 ab	100 a
At seedling emergence at 0.42 kg a.e. ha ⁻¹ ; apply three repeated applications at 0.42 kg a.e. ha ⁻¹ at 2-wk intervals	28 ef	62 cde	60 de	83 cd	97 abc	100 a	100 a
The end of the 2002 growing season	100 [‡] a	100 [‡] a	100 [‡] a	52 g	82 e	90 b	100 a
No glyphosate application until the spring of 2003	100 [‡] a	100 [‡] a	100 [‡] a	100 [‡] a	30 f	62 c	97 b
LSD (0.05)	22	16	14	8	7	8	1

[†] Values within each column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher's least significant difference test.

[‡] Values are percentages of a combination of Roundup Ready® creeping bentgrass and conventional turfgrass species.

SEEDING DATE AND SEEDING RATE INCREASE SPEED OF GOLF COURSE PUTTING GREEN
CONVERSION TO GLYPHOSATE-RESISTANT CREEPING BENTGRASS

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ADDITIONAL INDEX WORDS. genetically modified grass, intraseeding

Abstract

Establishment of golf course putting greens to glyphosate-resistant creeping bentgrass (*Agrostis stolonifera* L.) may lead to improved weed control. Conversion of putting greens to a different cultivar by using traditional conversion methods disrupts golf play for several months. The objectives of these field studies were to investigate surface-preparation methods, seeding dates, and seeding rates that might result in rapid conversion of putting greens to glyphosate-resistant creeping bentgrass. Glyphosate was applied 1 d before seeding glyphosate-resistant creeping bentgrass into a native-soil putting green previously established to 'Penncross' creeping bentgrass. A conversion experiment was initiated on 19 Aug. 2003 with three seeding rates, 2.4, 7.3, and 12.2 g m⁻² and four surface-preparation treatments: core aeration with vertical mowing, Graden[®] vertical mower, T.I.P. greens spiker/seeder[™], Terra Combi spiker, and a bare soil control. A separate conversion experiment researching seeding date was seeded with glyphosate-resistant creeping bentgrass at 7.3 g m⁻² on 19 Aug., 9 Sept., or 30 Sept. 2003 with the same surface-preparation treatments listed above. On 22 September, percentage cover was the same on plots seeded at 7.3 and 12.2 g m⁻², and 17% greater than plots seeded at 2.4 g m⁻² regardless of the preparation method. Plots seeded on 19 August had the greatest cover on 13 November, and

cover was 1.2- and 2.3-fold greater than that of plots seeded on 9 September and 30 September, respectively. All surface-preparation treatments provided similar glyphosate-resistant creeping bentgrass cover. Golf course putting green conversion to glyphosate-resistant creeping bentgrass was most rapid when seed was sown in late summer at 7.3 g m^{-2} .

Introduction

Creeping bentgrass (*Agrostis stolonifera* L.) is the principal turfgrass species used on golf course putting greens (Fry and Butler, 1989). It produces a dense canopy of turf ideal for golf play when mowed at putting green height. Most weeds cannot colonize swards of creeping bentgrass, but annual bluegrass (*Poa annua* L.) can persist in putting greens and become a dominant species (Gaussoin and Branham, 1989; Lush, 1989). Annual bluegrass is susceptible to many disease pathogens, cannot tolerate high temperatures or drought, and is subject to death during the winter (Beard, 1973). Its prolific seed production disrupts ball roll, and causes an undesirable putting surface (Lush, 1989). Effective control of annual bluegrass by using selective herbicides, plant growth regulators, or cultural controls has proven unsuccessful (Christians, 1996; Vargas and Turgeon, 2004). Creeping bentgrass cultivars that are resistant to glyphosate have recently been developed. Upon commercialization, glyphosate-resistant creeping bentgrass could enhance weed control in golf course putting greens, tees, and fairways, in particular through selective removal of annual bluegrass.

Conversion of putting greens to glyphosate-resistant creeping bentgrass would ease management and improve overall uniformity of the turfgrass. Traditional conversion techniques require application of a nonselective herbicide, removal of dead sod, and preparation of a seedbed sufficient for turfgrass establishment. Conversion of putting greens to more desirable cultivars is a labor-intensive process that can interrupt play for several

months, and this leads to a loss of revenue (Kendrick and Danneberger, 2002). An alternate conversion method is to seed the new cultivar into the existing turf. This establishment method decreases disturbance to the existing turfgrass and is less labor-intensive than other approaches; however, this at best allows for a slow conversion over a great number of years to the desired cultivar (Kendrick and Danneberger, 2002).

Researchers evaluating methods of seeding into existing turf have demonstrated that the competitive capacity of the existing turf hampers the establishment of new seedlings (Cattani, 2001; Kendrick and Danneberger, 2002; Reicher and Hardebeck, 2002).

Consequently, these researchers sought to measure and reduce competition. Competition from existing turf is minimized when seeding glyphosate-resistant creeping bentgrass as glyphosate can be applied prior to seeding and throughout establishment. Thus, the success and speed of conversion should therefore be contingent upon management practices used during seeding, such as methods used for surface preparation, seed date, and seeding rate.

Traditional surface-preparation methods implement core aeration followed by vertical mowing (Kraft et al., 2004). Large soil gaps produced by this equipment may improve seedling survival during conversion as larger gaps reduce competition from surrounding turf (Kendrick and Danneberger, 2002). However, competition is not a major factor when seeding glyphosate-resistant creeping bentgrass with concomitant application of glyphosate. Therefore, the use of alternate pieces of equipment that create smaller, more uniformly distributed soil gaps, and cause less surface disruption may speed conversion and reduce the duration of the interruption of play.

Major conversion projects in the Midwestern U.S. often are started after Labor Day (approximately 1 September) to reduce revenue loss and interruption of golf course play (Reicher and Hardebeck, 2002). Unfortunately, this may not be the best time to begin the conversion of a putting green. Soil temperatures can become too low for adequate

germination and immature seedlings are more sensitive to the winter climate compared with mature plants (Beard, 1973).

Increasing seeding rates above recommended levels may speed the conversion process. Some researchers have reported greater success with higher-than-normal seeding rates (Kraft et al., 2004), whereas others have found that increased rates have little effect on the speed of conversion (Reicher and Hardebeck, 2002).

Our objective was to evaluate how different methods of surface preparation, seeding date, and seeding rate affect the conversion speed of an established putting green to glyphosate-resistant creeping bentgrass.

Materials and Methods

We conducted two experiments on a native-soil putting green previously established to 'Penncross' creeping bentgrass with an immeasurable thatch layer. The putting green was located at the Iowa State University Horticulture Research Station near Gilbert, IA. Soil was a Nicollet (fine-loamy, mixed, mesic-Aquic Hapludolls) with a pH of 7.4, 34 g kg⁻¹ organic matter, 9 mg kg⁻¹ P, and 71 mg kg⁻¹ K. One experiment was conducted to investigate seeding rate with each of five surface-preparation methods and a second to examine seeding dates with each surface-preparation method. Treatments of both experiments were arranged in a split-plot design with three replications. Main plots (surface-preparation treatment) measured 2.4 x 4.6 m and were arranged in a randomized complete block design. Split-plots (seeding rate or seeding date) measured 1.5 x 2.4 m and were randomized within each main plot. Four surface-preparation treatments were studied. A bare-soil seedbed served as a control and the fifth main plot. Seeding at 2.4, 7.3, and 12.2 g m⁻² was evaluated in one experiment and seeding dates of 19 August, 9 September, and 30 September in the other.

Glyphosate-resistant creeping bentgrass seed, line ‘ARS 368’, was obtained from The Scotts Company (Marysville, OH). Seed was approximately 75% glyphosate-resistant by weight. Seeding rates were adjusted to 3.2, 9.7, and 16.3 g m⁻² to compensate for the proportion of seed not resistant to glyphosate. To ease sowing of seed, greens-grade Milorganite[®] (6N-0.9P-0K) (Milwaukee Metropolitan Sewerage District, Milwaukee, WI) was blended with the seed to supply N at 2.4 g m⁻². For all treatments, seed was sown by hand using a “shaker dispenser”. The area was mowed daily at 3.8 mm before initiation of the experiments. Clippings were collected before initiation of treatments and throughout each study.

Seeding-rate Experiment

Treatment application. On 5 Aug. 2003, we applied glyphosate at 1.26 kg a.e. ha⁻¹ to existing turf on what was to become the bare-soil plots. All turf and thatch were removed 1 wk later, and a tiller was used to prepare a seedbed. Glyphosate was applied to all other plots on 18 August at 1.26 kg a.e. ha⁻¹. On 19 August, all surface-preparation treatments were applied, and glyphosate-resistant creeping bentgrass seed was sown on split-plots at 2.4, 7.3, and 12.2 g m⁻².

The four surface-preparation treatments included: (i) core aerification with vertical mowing, (ii) the Graden[®] vertical mower, (Graden Industries, Victoria, Australia); (iii) the T.I.P. greens spiker/seeder[™] (Turf Improvement Products, Inc., Custer, WI), and (iv) the Terra Combi spiker (Wiedenmann North America LLC, Savannah, GA).

A Ryan[®] GA[™]-30 aerator (Jacobsen, Charlotte, NC) (Table 1) was used for the core aerification with vertical-mowing treatment. We removed all aerification cores before a Toro[®] Greensmaster[®] 3100 (The Toro Company, Bloomington, MN) (Table 1) equipped with verticutting units was applied to the plot twice in perpendicular directions. Seed was

sown, and the surface was smoothed by topdressing with sand to a depth of 6 mm. All sand conformed to USGA (United States Golf Association, Far Hills, NJ) specifications.

The Graden[®] vertical mower treatment (Table 1) was applied to plots twice by running the machine across the plot in perpendicular directions. Plots were seeded, then topdressed with sand to a depth of 4 mm.

The Terra Combi spiker treatment (Table 1) was implemented by running the machine across the plot, and then one-half of the seed was sown. We applied a second pass across the plot in the opposite direction. The remaining portion of the seed was then sown, and plots were spiked for a third time. After the final pass of the Terra Combi spiker, 2 mm of topdressing sand was applied to the plot.

Application of the T.I.P. greens spiker/seed[™] treatment (Table 1) and sowing of seed were conducted in the same manner as with the Terra Combi spiker. Plots also were topdressed with 2 mm of sand after the final pass of the spiker.

Metalaxyl was applied to all plots at 0.7 kg ha⁻¹ in the form of Subdue[®] GR (Syngenta Crop Protection, Inc., Greensboro, NC) after preparation of the surface, sowing of seed, and topdressing. Irrigation was applied as necessary in light and frequent applications to promote seed germination. Glyphosate was applied at 1.26 kg a.e. ha⁻¹ 3 wk after seeding to remove any seedlings not resistant to glyphosate and any 'Penncross' creeping bentgrass that had recovered from the initial application of glyphosate.

Fertilization and mowing. The fertility program described in Table 2 was used during establishment of glyphosate-resistant creeping bentgrass. Seedlings had reached a height of 13.3 mm at 2 wk after seeding, and plots were then mowed at 12.7 mm three times per week. The height of mowing was reduced to 10.2 mm at 4 wk after seeding, 8.9 mm at 8 wk after seeding, and 8.3 mm at 10 wk after seeding. Mowing in the following spring resumed on 23 Apr. 2004 at 7.6 mm, and was reduced to a final height of 4.4 mm on 5 June.

Seeding-date Experiment

Treatment application. We applied glyphosate to existing turf on what were to become bare-soil plots at 1.26 kg a.e. ha⁻¹ on 5 Aug. 2003. One week later, all turf and thatch were removed, and soil was tilled for the bare-soil (control) treatment. Glyphosate was applied at 1.26 kg a.e. ha⁻¹ 1 d before each respective seeding date for all other surface-preparation treatments.

We seeded glyphosate-resistant creeping bentgrass on 19 August, 9 September, and 30 September at 7.3 g m⁻². All surface-preparation treatments were applied to split-plots on the day of seeding. Surface preparation, metalaxyl application, topdressing, and irrigation were similar to those described previously for the seeding-rate experiment. As with the seeding-rate experiment, we applied glyphosate at 1.26 kg a.e. ha⁻¹ to remove any ‘Penncross’ creeping bentgrass that had recovered and seedlings not tolerant to glyphosate. This application was made to split-plots 3 wk after seed was sown.

Fertilization and mowing. The same fertilizer schedule was used for this experiment (Table 2). Split-plots were fertilized independently according to the date seeds were sown. When seedlings reached 13.3 mm, we initiated mowing at 12.7 mm. Plots seeded on 19 August, 9 September, and 30 September were mowed for the first time on 3 September, 12 October, and 7 November, respectively. The height of mowing was reduced to 10.2 mm at 4 wk after seeding, 8.9 mm at 8 wk after seeding, and 8.3 mm at 10 wk after seeding on all plots seeded 19 August. Mowing height of plots seeded on 9 September and 30 September was maintained at 13.3 mm for the remainder of the 2003 growing season. All plots were mowed on 24 Apr. 2004 at a height of 7.6 mm, and a final mowing height of 4.4 mm was reached on 5 June.

Data Collection and Analysis

Percentage cover was visually estimated on the 1.5- x 2.4-m plots. Percentage cover was recorded on 3 Sept., 22 Sept., 7 Oct., and 28 Oct. 2003 (3, 5, 7, and 10 wk after seeding) for the seeding-rate experiment and 13 Nov. 2003, 6 Apr., 21 Apr., 5 May, and 18 May 2004 (12, 33, 35, 37, and 39 wk after the first seeding) for the seeding-date experiment, respectively. Data were analyzed by using the Mixed Linear Model procedure of the Statistical Analysis System (SAS, 1999-2001). Surface preparation, seeding rate, and seeding date were analyzed as fixed effects with blocks random. Contrasts were used to make comparisons between means for surface-preparation main effects. Mean comparisons for seeding rate and seeding date main effects, as well as for all interactions, were made by using an *F*-protected least significant difference test calculated according to Little and Hills (1972). All tests of significance were made at the $P \leq 0.05$ level.

Results

Seeding-rate Experiment

Higher seeding rates resulted in more rapid cover of glyphosate-resistant creeping bentgrass (Fig. 1). Plots seeded at 7.3 and 12.2 g m⁻² had 1.9- and 2.2-fold greater cover than did plots seeded at 2.4 g m⁻² on 3 Sept. 2003, 3 wk after seeding. All seeding rates had turf cover \geq to 97% at week ten (Fig. 1).

The greatest differences among surface-preparation treatments occurred 3 wk after seeding (Tables 3 and 4). At that time, T.I.P. greens spiker/seederTM, Terra Combi spiker, and bare-soil treatments produced turf cover that was 41% ($P = 0.0142$), 49% ($P = 0.0053$), and 61% ($P = 0.0013$) greater than turf cover after core aeration with vertical mowing, respectively (Table 4). All surface-preparation treatments achieved glyphosate-resistant

creeping bentgrass cover > 97%, and all treatments were similar on week ten (Tables 3 and 4).

Percentage cover of glyphosate-resistant creeping bentgrass 5 and 7 wk after seeding was greatest on bare-soil and Terra Combi spiker plots when 2.4 g m⁻² of seed was sown (Tables 4). When glyphosate-resistant creeping bentgrass was seeded at 7.3 and 12.2 g m⁻², the resulting cover at week five and seven was lowest on plots treated by core aerification with vertical mowing. Cover achieved on plots treated with the T.I.P. greens spiker/seedersTM or core aerification with vertical mowing was similar 7 wk after seeding when seed was sown at 7.3 g m⁻².

Seeding glyphosate-resistant creeping bentgrass at 7.3 and 12.2 g m⁻² resulted in greater percentage cover than did seeding at the lowest rate for all surface-preparation treatments at weeks five and seven with the exception of the bare soil treatment at week seven (Table 4).

Seeding-date Experiment

Conversion to glyphosate-resistant creeping bentgrass was most rapid when seeding occurred on 19 Aug. 2003 (Fig. 2). On 13 Nov. 2003, 12 wk after the first seeding, turf cover was 99, 83, and 44% on plots seeded 19 August, 9 September, and 30 September, respectively. Percentage glyphosate-resistant creeping bentgrass cover at week 35 for the seeding dates 19 August and 9 September were not significantly different, but greater than percentage cover for the 30 September seeding date (Fig. 2).

The bare-soil treatment and plots that were core aerified and vertically mowed achieved the greatest glyphosate-resistant creeping bentgrass cover 33 wk after the first seeding when seeded on 19 August (Tables 5 and 6). All other surface-preparation treatments on week 33 had the greatest cover when seeded on either 19 August or 9

September. Thirty-seven weeks after the first seeding, turf cover of plots seeded on 19 August or 9 September for all surface-preparation methods was greater than when seeding occurred on 30 September. For all surface-preparation treatments on all observation dates, plots seeded on 30 September resulted in the lowest glyphosate-resistant creeping bentgrass cover with the exception of the Graden[®] vertical mower 39 wk after the first seeding (Table 6).

When seeding occurred on 19 August, surface preparation did not affect establishment of glyphosate-resistant creeping bentgrass (Table 6). This was also true 37 and 39 wk after the first seeding when seed was sown on 9 September. When seeding occurred on 30 September, the method of surface preparation impacted turf establishment on weeks 33, 35, and 39. These differences were most pronounced 39 wk after the first seeding. Plots treated with the Graden[®] vertical mower had the greatest cover, 55% greater than cover on bare-soil plots (Table 6).

Discussion

Seeding at 7.3 g m⁻² is optimal for conversion of an established putting green to glyphosate-resistant creeping bentgrass. Additionally, we found that establishment is most rapid when seeding occurred on 19 August. Surface-preparation method had little or no effect on glyphosate-resistant creeping bentgrass establishment.

Beard (1973) recommends seeding at 2.4 to 4.9 g m⁻² for initial establishment of creeping bentgrass. We found that seeding at 7.3 and 12.2 g m⁻² increased the speed of establishment. Kraft et al. (2004) reported that increasing seeding rates above recommended levels improved the success of converting a perennial ryegrass (*Lolium perenne* L.) fairway to Kentucky bluegrass (*Poa pratensis* L.). Our results indicate that seeding at 12.2 g m⁻² was excessive. Although glyphosate-resistant creeping bentgrass cover was greater on plots

seeded at 12.2 g m^{-2} shortly after seeding, turf cover on plots seeded at 7.3 g m^{-2} quickly increased to levels similar to cover resulting from the higher rate. These findings are consistent with those of Reicher and Hardebeck (2002) who reported that seeding creeping bentgrass at 9.8 g m^{-2} was not advantageous to seeding at 4.9 g m^{-2} when converting a fairway previously established to annual bluegrass, Kentucky bluegrass, and perennial ryegrass. Madison (1966) also reported that higher seeding rates for initial establishment of creeping bentgrass did not result in greater establishment. Additionally, Madison (1966) found that excessive seeding rates resulted in competition between seedlings, resulting in immature, weak turfgrass stands that were susceptible to disease.

Beginning the conversion of existing putting greens to glyphosate-resistant creeping bentgrass on 19 August resulted in the most rapid establishment. The optimal seeding period for cool-season turfgrasses is late summer when soil temperature is favorable (Beard, 1973; Watschke and Schmidt, 1992). This period is from mid-August to mid-September in Iowa. Generally, golf course revenue decreases after 1 September (Reicher and Hardebeck, 2002), and therefore, it would be beneficial to conduct putting-green conversions after this date. However, our results indicate that seeding earlier than 1 September speeds the establishment of glyphosate-resistant creeping bentgrass. Golf courses should take this into consideration when comparing the benefits of starting the conversion in late summer with the resulting loss of revenue and disruption of play. Interruption to golf play during the late summer months could allow resumption of golf play earlier in the spring and provide a more uniform putting surface for golfers.

We found that methods used to prepare existing turf for seeding had little impact on the establishment speed of glyphosate-resistant creeping bentgrass. Core aeration with vertical mowing is a common method used for seeding into existing turf; however, we observed that it causes significant surface disruption and is more labor-intensive than use of

the other pieces of equipment evaluated. The resulting aerification holes were much larger than bentgrass seeds and large amounts of thatch and soil were removed, leaving few gaps for seed placement. Using alternative equipment, which produce many smaller, more evenly distributed soil openings, appears to be a more viable option for rapid conversion of existing putting greens to glyphosate-resistant creeping bentgrass.

Our results indicate that conversion of established putting greens can be accomplished by seeding into existing turf as opposed to removing the existing turf and thatch and preparing a seedbed. However, the success of conversion to glyphosate-resistant creeping bentgrass is dependent on the removal of competition through preemergence and postemergence glyphosate applications (Dant and Christians, 2005; Kendrick and Danneberger, 2002). Leaving the existing turf intact maintains the surface contour of the putting green, controls erosion, and provides a stable surface for mowing of new seedlings. Additionally, the high cost, extended period of time, and labor required to prepare a seedbed are avoided.

We used high levels of N fertilization to establish glyphosate-resistant creeping bentgrass (Table 2). Beard (2002) recommends supplying N at 1.5 to 2.9 g m⁻² applied on a 7- to 10-d interval. We applied N at 2.4 to 4.9 g m⁻² wk⁻¹ during the first 6 wk after seeding. Increasing N fertility hastens turfgrass establishment, but excessive amounts can have negative long-term effects (Turner and Hummel, 1992). Additionally, excess N not absorbed by the plant could leach and/or run off, adversely affecting the environment. More research is required to evaluate the effect of various N rates on speed of establishment during conversions.

In these experiments, the final mowing height of the putting green was not reached until 5 June 2004. We believe putting green height could have been attained sooner, but we cannot be sure what effect lower mowing heights would have had on the speed at which

glyphosate-resistant creeping bentgrass established. Mowing is a stress to the turfgrass plant (Beard, 1973). Consequently, lowering the mowing height could impact the speed of conversion negatively. A more complete understanding of mowing practices during conversion of existing putting greens to glyphosate-resistant creeping bentgrass is required, and it should be the goal of future research.

In conclusion, a rapid conversion of existing putting greens to glyphosate-resistant creeping bentgrass occurred with all methods of surface preparation when seed was sown on 19 August and glyphosate-resistant creeping bentgrass was seeded at 7.3 g m⁻² or greater. Seeding on 19 August is not applicable in all situations or for all areas of the upper Midwest. However, we are confident that if a putting green conversion is started during late summer, rather than in the fall, the converted putting green will more quickly establish and be ready for golf play earlier in the following spring.

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Table 1. Specifications for surface-preparation treatments used to convert a native-soil putting green from ‘Penncross’ creeping bentgrass to glyphosate-resistant creeping bentgrass.

Specifications	Equipment				
	Toro [®] Greensmaster [®] 3100	Ryan [®] GA [™] -30 aerator	Graden [®] vertical mower	T.I.P. greens spiker/seeders [™]	Terra Combi spiker
Tine type	---	hollow	---	solid	solid
Tine diam. (mm)	---	16	---	5	5
Tine length (mm)	---	50	---	25	64
Tine spacing (mm)	---	64 x 50	---	38 x 38	25 x 25
Vertical blade thickness (mm)	1	---	2	---	---
Vertical blade spacing (mm)	13	---	25	---	---
Penetration depth (mm)	3	50	13	13	25

Table 2. Fertilizer application schedule used to convert a native-soil putting green established to 'Penncross' creeping bentgrass to glyphosate-resistant creeping bentgrass.

Fertilizer (N-P-K)	Time of application (weeks after seeding)	N	P	K
		g m ⁻²		
19-11-4	0	4.9	2.8	1.1
19-11-4	1	4.9	2.8	1.1
18-4-15	2	3.7	0.8	3.0
19-11-4	3	3.7	2.1	0.8
18-4-15	4	3.7	0.8	3.0
18-4-15	5	2.4	0.5	2.0
18-4-15	6	2.4	0.5	2.0

Table 3. Analysis of variance for effects of surface preparation and seeding rate on conversion of native-soil putting green from 'Penncross' creeping bentgrass to glyphosate-resistant creeping bentgrass. Glyphosate was applied to existing turf on 18 Aug. 2003 at 1.26 kg a.e. ha⁻¹. Glyphosate-resistant creeping bentgrass was seeded on 19 Aug. 2003 at 2.4, 7.3, and 12.2 g m⁻².

Source of variation	Time after seeding (weeks)			
	3	5	7	10
	<i>F</i> -ratio			
Surface preparation (S)	6.73*	10.61**	5.55*	2.10 ^{NS}
Seeding rate (R)	201.48**	190.90**	89.87**	13.13**
S x R	1.63 ^{NS}	11.13**	6.00**	0.83 ^{NS}

*, **, and ^{NS} indicate significance at $P = 0.05$, $P = 0.01$, and not significant, respectively.

Table 4. Surface preparation and seeding rate affect conversion of a native-soil putting green from 'Penncross' creeping bentgrass to glyphosate-resistant creeping bentgrass. Glyphosate was applied to existing turf on 18 Aug. 2003 at 1.26 kg a.e. ha⁻¹, and glyphosate-resistant creeping bentgrass was seeded on 19 Aug. 2003 at 2.4, 7.3, and 12.2 g m⁻². Values are means from three replications. Percentage cover was estimated by visual observation of 1.5- x 2.4-m plots.

Surface-preparation treatment Seeding rate (g m ⁻²)	Time after seeding (weeks)			
	3	5	7	10
	%			
Bare Soil [†]				
2.4	58 [‡]	93	96	98
7.3	83	98	99	99
12.2	96	100	100	100
Core aeration with vertical mowing				
2.4	23	75	83	96
7.3	57	92	93	99
12.2	68	92	95	99
Graden [®] vertical mower				
2.4	27	75	83	97
7.3	73	98	99	100
12.2	88	100	100	100
T.I.P. greens spiker/seeders [™]				
2.4	42	82	85	95
7.3	73	97	98	99
12.2	91	99	100	100
Terra Combi spiker				
2.4	47	90	95	99
7.3	80	99	99	100
12.2	92	97	100	100

[†]Existing turf was removed, and seed was sown into soil.

[‡]LSD ($P \leq 0.05$) for seeding rate with same surface-preparation treatment = NS, 4, 4, and NS for weeks 3, 5, 7, and 10, respectively. Surface-preparation treatment with the same seeding rate = NS, 5, 6, and NS for weeks 3, 5, 7, and 10, respectively.

Table 5. Analysis of variance for effects of surface preparation and seeding date on conversion of a native-soil putting green from 'Penncross' creeping bentgrass to glyphosate-resistant creeping bentgrass. Glyphosate was applied at 1.26 kg a.e. ha⁻¹ to existing turf 1 d before seeding. Glyphosate-resistant creeping bentgrass was seeded on 19 Aug., 9 Sept., and 30 Sept. 2003 at 7.3 g m⁻².

Source of variation	Time after first seeding (weeks) [†]			
	33	35	37	39
	<i>F</i> -ratio			
Surface preparation (S)	0.66 ^{NS}	1.22 ^{NS}	10.11 ^{**}	2.72 ^{NS}
Seeding date (D)	222.15 ^{**}	118.28 ^{**}	151.48 ^{**}	35.87 ^{**}
S x D	3.22 [*]	1.13 ^{NS}	3.08 [*]	2.69 ^{**}

[†]Weeks after first seeding are from the seeding date 19 Aug. 2003. Thirty-three weeks after the first seeding was 6 Apr. 2004.

^{*}, ^{**}, and ^{NS} indicate significance at $P = 0.05$, $P = 0.01$, and not significant, respectively.

Table 6. Surface preparation and seeding date affect conversion of a native-soil putting green from 'Penncross' creeping bentgrass to glyphosate-resistant creeping bentgrass. Glyphosate was applied to existing turf at 1.26 kg a.e. ha⁻¹ 1 d before seeding. Glyphosate-resistant creeping bentgrass was seeded on 19 Aug., 9 Sept., and 30 Sept. 2003 at 7.3 g m⁻². Values are means from three replications. Percentage cover was estimated by visual observation of 1.5- x 2.4-m plots.

Surface-preparation treatment	Time after first seeding (weeks) [†]			
	33	35	37	39
Seeding date	%			
Bare soil [‡]				
19 Aug.	98 [§]	98	100	100
9 Sept.	80	87	90	89
30 Sept.	48	55	55	58
Core aeration with vertical mowing				
19 Aug.	98	99	100	100
9 Sept.	80	92	95	98
30 Sept.	37	52	67	77
Graden [®] vertical mower				
19 Aug.	100	99	99	100
9 Sept.	88	95	97	97
30 Sept.	47	73	82	90
T.I.P. greens spiker/seeder [™]				
19 Aug.	100	100	100	100
9 Sept.	96	95	98	99
30 Sept.	27	57	75	78
Terra Combi spiker				
19 Aug.	99	100	100	100
9 Sept.	95	95	97	100
30 Sept.	28	53	70	73

[†]Time after first seeding is from the seeding date 19 Aug. 2003. Thirty-three weeks after the first seeding was 6 Apr. 2004.

[‡]Existing turf was removed, and seed was sown into soil.

[§]LSD ($P \leq 0.05$) for seeding date with same surface-preparation treatment = 14, NS, 13, and 8 for weeks 33, 35, 37, and 39, respectively. Surface-preparation treatment with the same seeding date = 15, NS, 14, and 11 for weeks 33, 35, 37, and 39, respectively.

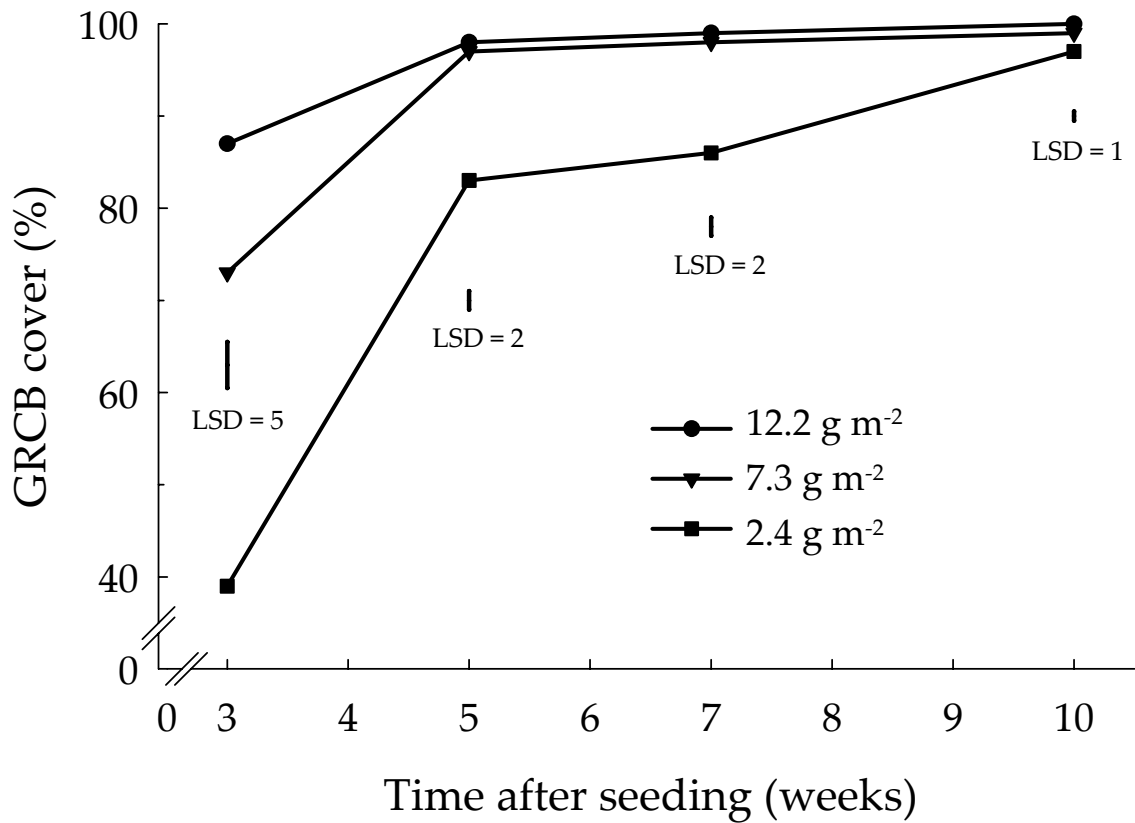


Figure 1. Greater seeding rates resulted in a more rapid conversion to glyphosate-resistant creeping bentgrass (GRCB) than lower seeding rates on a native-soil putting green previously established to ‘Penncross’ creeping bentgrass. Glyphosate was applied to existing turf on 18 Aug. 2003 at 1.26 kg a.e. ha⁻¹ and glyphosate-resistant creeping bentgrass was seeded on 19 Aug. 2003. Values are means averaged across surface-preparation-treatment main effects from three replications. Percentage cover was estimated by visual observation of 1.5- x 2.4-m plots. Least significant difference (LSD) values for 3, 5, 7, and 10 wk after seeding were determined at $P \leq 0.05$.

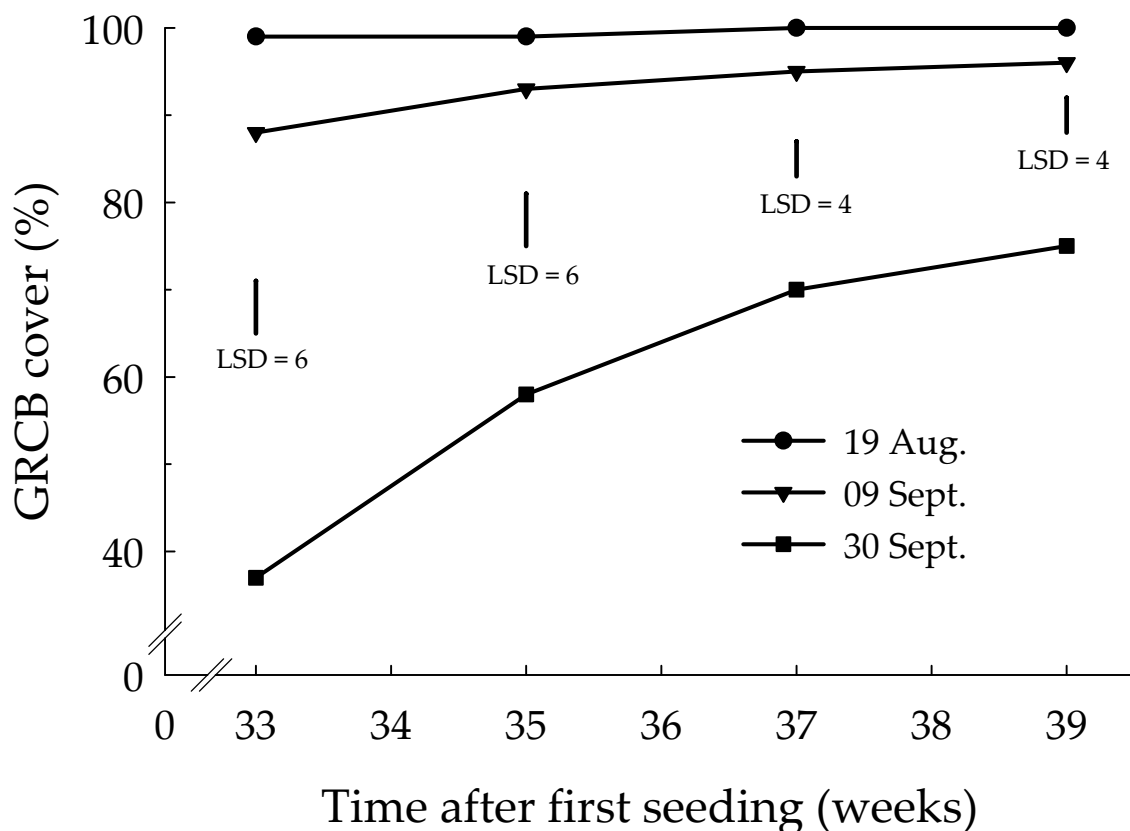


Figure 2. Earlier seeding dates resulted in greater glyphosate-resistant creeping bentgrass (GRCB) cover than did later dates on a native-soil putting green previously established to ‘Penncross’ creeping bentgrass. Glyphosate-resistant creeping bentgrass was seeded at 7.3 g m⁻² on 19 Aug., 9 Sept., and 30 Sept. 2003. Glyphosate was applied at 1.26 kg a.e. ha⁻¹ to existing turf 1 d before seeding. Values are means averaged across surface-preparation-treatment main effects from three replications. Percentage cover was estimated by visual observation of 1.5- x 2.4-m plots. Time after first seeding is from the seeding date 19 Aug. 2003. Thirty-three weeks after the first seeding was 6 Apr. 2004. Least significant difference (LSD) values for 33, 35, 37, and 39 wk after the first seeding were determined at $P \leq 0.05$.

**SEEDLING MOWING HEIGHT, NITROGEN FERTILITY, AND SEEDING DATE FOR RAPID
CONVERSION OF GOLF COURSE PUTTING GREEN CONVERSION TO GLYPHOSATE-RESISTANT
CREEPING BENTGRASS**

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ADDITIONAL INDEX WORDS. establishment, transgenic turfgrass, seeding date

Abstract

Conversion of established golf course putting greens to glyphosate-resistant creeping bentgrass (*Agrostis stolonifera* L.) could ease weed management and improve overall quality of the putting surface. To minimize disruption of golf play, methods that speed conversion of putting greens are needed. Research was conducted to evaluate seeding dates, mowing regimes, and N fertility levels that result in rapid conversion of established putting greens to glyphosate-resistant creeping bentgrass. Glyphosate-resistant creeping bentgrass was seeded at 7.3 g m⁻² on 16 Aug., 1 Sept., 17 Sept., and 30 Sept. 2004 into a native-soil putting green previously established to ‘Crenshaw’ creeping bentgrass. Glyphosate was applied 1 d before each seeding date to kill existing turf. Three combinations of initial mowing heights and subsequent mowing height reductions were investigated, as well as N fertility rates of 1.2 and 2.4 g m⁻². Plots seeded on 16 August established most rapidly. Putting green conversion was most rapid when seedlings were cut at 6.4 mm and glyphosate-resistant creeping bentgrass was permitted to reach approximately 100% cover before lowering the mowing height 0.76 mm wk⁻¹. No differences were observed between N fertility levels. When seeding occurred

on 16 August and the mowing regime described above was implemented, the putting green was deemed acceptable for golf play on 29 Oct. 2004.

Introduction

Creeping bentgrass (*Agrostis stolonifera* L.) is commonly grown on golf course putting greens in temperate regions of the U.S (Fry and Butler, 1989). Creeping bentgrass putting greens are maintained at mowing heights as low as 3 mm (Gardner et al., 2004) and when creeping bentgrass is managed properly, its fine leaf texture and dense tiller production form a surface ideal for golf play. Annual bluegrass (*Poa annua* L.) invades creeping bentgrass as putting greens age and can establish a significant population (Gaussoin and Branham, 1989; Lush, 1989). Annual bluegrass is a problematic weed because of its low heat and drought tolerance and its susceptibility to winterkill (Beard, 1973). Also, it produces a flush of seedheads that disrupts turf uniformity and destroys putting green aesthetics (Lush, 1989). Effective means for the control of annual bluegrass currently do not exist (Christians, 1996; Gardner et al., 2004).

Genetically transformed creeping bentgrass cultivars have been developed that are resistant to the nonselective herbicide glyphosate. To date, glyphosate-resistant creeping bentgrass is not commercially available, but its use could ease weed control, in particular the removal of annual bluegrass. This advance presents golf course superintendents with the opportunity to convert existing putting greens to glyphosate-resistant creeping bentgrass. Conversion of an established putting green to a more desirable cultivar requires several months (Kendrick and Danneberger, 2002). Interruption to golf play and revenue loss are an inevitable consequences of the conversion process. Therefore, methods that increase conversion speed of are needed. Past research at Iowa State University has shown that putting greens can be converted to glyphosate-resistant creeping bentgrass by seeding

directly into turf killed by glyphosate (unpublished data, 2004). In this past study, seed was sown in mid-August 2003 and it was estimated that play could resume during the first week of June 2004.

Major conversion projects in the Midwestern U.S. are often started after Labor Day (approximately 1 September) to reduce revenue loss and disruption of play during the peak of the golf season (Reicher and Hardebeck, 2002). Soil temperatures at this time begin to decrease and may impede seed germination. Even when germination does occur, cold temperatures may not allow seedlings to mature before winter. Immature seedlings are more susceptible to the harsh winter climate than their mature counterparts (Beard, 1973). Research conducted at Iowa State University has suggested that seeding in mid-August rather than later in the fall increases the success of putting green conversion to glyphosate-resistant creeping bentgrass (unpublished data, 2004).

In the conversion experiment cited previously, the converted putting green had 100% glyphosate-resistant creeping bentgrass cover in October, approximately two months after seeding, but turf height was 8.3 mm, much greater than the desired mowing height (3-4 mm) of established putting greens. Putting green height in this study was not achieved until June of the following spring.

It is generally accepted that overall turfgrass health is increased as the mowing height is raised. As the height of cut is reduced, carbohydrate production and storage is decreased, as is root growth rate and production (Beard, 1973). Additionally, low mowing heights cause a reduction in creeping bentgrass quality, root biomass and stress tolerance (Salaiz, et al., 1995; Fagerness et al., 2000; Fagerness and Yelverton, 2001). For these reasons, it is conceivable that establishment of putting greens converted to glyphosate-tolerant creeping bentgrass would be more rapid when mowing of seedlings is initiated at greater heights.

In theory, an argument can also be made that moderately low mowing heights may speed glyphosate-resistant creeping bentgrass establishment. Tiller production and shoot density increase at lower mowing heights in creeping bentgrass, Kentucky bluegrass (*Poa pratensis* L.), and perennial ryegrass (*Lolium perenne* L.) turf (Krans and Beard, 1975; Lush and Rogers, 1992; Fagerness et al., 2000). Stolon production also increases as mowing height decreases (Beard, 1973). Additionally, when the initial mowing height of seedlings is raised, greater defoliation must occur to reduce turfgrass to heights acceptable for golf play. Ideally, there is a balance between stimulating creeping bentgrass horizontal growth and reducing the stress caused by mowing.

An additional approach used to speed turfgrass establishment is to increase N fertility (Turner and Hummel, 1992; White, 2000). However, as N fertilization increases so does the incidence of disease, especially Pythium blight (*Pythium* spp.) (White, 2000; Beard, 2002). Excessive N fertilization over-stimulates shoot growth at the expense of root production (Beard, 1973). Also of concern is the potential that N not utilized by the turfgrass plant may run off and/or leach through the soil profile.

The objectives of this experiment were to evaluate how (i) seeding date; (ii) initial mowing height and subsequent mowing height reduction; and (iii) N fertility level affect conversion speed of established putting greens to glyphosate-resistant creeping bentgrass.

Materials and Methods

This experiment was conducted at the Iowa State University Horticultural Research Station located near Gilbert, IA on a native-soil putting green that had been established to 'Crenshaw' creeping bentgrass 1 yr before initiation of this experiment. The soil was a Nicollet (fine-loamy, mixed, mesic-Aquic Hapludolls) with a pH of 7.5, 38 g kg⁻¹ organic matter, 4 mg kg⁻¹ P, and 67 mg kg⁻¹ K. The experimental design was a split-split-plot. Main

plots (seeding date) were arranged in a randomized complete block design and measured 4.6 x 3 m. Split-plots (mowing regime) measured 3 x 1.5 m and were randomized within each main plot. Split-split plots (N fertility level) were 1.5 x 1.5 m and randomized within each split-plot.

Seeding

Seeding dates of 16 Aug., 1 Sept., 17 Sept., and 30 Sept. 2004 were investigated in the experiment. We applied glyphosate at 1.26 kg ha⁻¹ to main plots 1 d before seeding. The T.I.P. greens spiker/seeder™ (Turf Improvement Products, Inc., Custer, WI) was used to prepare the surface for seeding. It was equipped with 5-mm diam. solid tines measuring 25 mm in length. Tine spacing was 38 x 38 mm and tines penetrated into the soil approximately 13 mm. The spiker was applied to the plots and one-half of the seed was sown. After a second pass of the spiker, the remaining seed was sown and plots were spiked again to promote seed-to-soil contact. Seeds were sown by hand using “shaker dispensers”. The plots were topdressed with sand to a depth of 4 mm and sand was brushed in to smooth the surface. Topdressing sand conformed to USGA (United States Golf Association, Far Hills, NJ) specifications. We applied a 19-11-4 (N-P-K) starter fertilizer supplying N at 2.4 g m⁻², and metalaxyl at 0.7 kg ha⁻¹ in the form of Subdue® GR (Syngenta Crop Protection, Inc., Greensboro, NC) after topdressing.

Glyphosate-resistant creeping bentgrass seed, line ‘R-EDI’, was seeded at 7.3 g m⁻². Seed was obtained from the Scotts Company (Marysville, OH) and was approximately 75% glyphosate-resistant by weight. The seeding rate was increased to 9.7 g m⁻² to compensate for the proportion of seeds not resistant to glyphosate. To ease sowing of seed, greens-grade Milorganite® (6N-0.9P-0K) (Milwaukee Metropolitan Sewerage District, Milwaukee, WI) was blended with the seed to supply N at 2.4 g m⁻². Glyphosate was applied at 1.26 kg a.e.

ha⁻¹ 21 d after germination to remove seedlings not resistant to glyphosate and any ‘Crenshaw’ creeping bentgrass that had recovered.

Mowing Regimes

All stated mowing heights reference the bench setting of the mower. Mowing regimes comprised of the following: (i) mowing was initiated at 6.4 mm when seedlings reached 7 mm, height of cut was reduced at a rate of 0.76 mm wk⁻¹; (ii) mowing began at 6.4 mm when seedlings reached 7 mm, height of cut was reduced at a rate of 0.76 mm wk⁻¹ when plots reached approximately 100% turf cover; and (iii) mowing was initiated at 12.7 mm when seedlings reached 13.3 mm, after plots had achieved approximately 100% turf cover, the height of cut was reduced at a rate of 1.5 mm wk⁻¹. The dates that mowing heights were reduced are presented in Table 1.

We mowed plots approximately 3 times wk⁻¹ at mowing heights between 5 and 13 mm. After the height of cut was reduced to or below 5 mm, plots were mowed approximately 5 times wk⁻¹. Mowing ceased on 5 Nov. 2004 and began the following spring on 15 Apr. 2005. When the height of cut reached 3.3 mm, plots were maintained at that height for the remainder of the study. The experimental area was mowed daily at 3.8 mm before initiation of the experiment. Clippings were collected before initiation of treatments and throughout the study.

Fertility Treatments

Nitrogen fertility treatments began 1 wk after seeding and were made weekly supplying N at 1.2 or 2.4 g m⁻². Coron[®] liquid fertilizer (22N-1.3P-2.5K) (Helena Chemical Company) was used for all N treatments. Plots seeded on 16 August, 1 September, 17 September, and 30 September received seven, seven, six, and four fertilizer applications

during the fall of 2004, respectively. Two additional fertilizer applications were made to all plots on 5 May and 21 May 2005 supplying N at 1.6 g m^{-2} .

Data Collection and Analysis

Percentage cover of glyphosate-resistant creeping bentgrass was estimated by visual observation of 1.5- x 2.4-m plots on 8 Oct. and 29 Oct. 2004, and 15 Apr., 6 May, and 27 May 2005. Cover of plots seeded on 17 September was not estimated on 8 October because of slow seed germination. Glyphosate-resistant creeping bentgrass cover of plots seeded on September 30 was not recorded on 8 October and 29 October for the same reason. Only observations made on these two dates were included in the statistical analysis. Data were analyzed by using the Mixed Linear Model procedure of the Statistical Analysis System (SAS, 1999-2001). Seeding date, mowing regime, and N fertility level were analyzed as fixed effects with blocks random. Mean comparisons for seeding date and mowing regime main effects, as well as for all interactions were made by using an *F*-protected least significant difference test calculated according to Little and Hills (1972). Means for N fertility levels were separated by using the *F*-ratio obtained from the analysis of variance. All tests of significance were made at the $P \leq 0.05$ level.

Results and Discussion

No interactions were present on observation dates 8 Oct 2004, 6 May, and 27 May 2005. Data presented for these dates have been averaged across all factors for each respective main effect (Table 2). A significant seeding date x mowing regime interaction occurred when glyphosate-resistant creeping bentgrass cover was estimated on 29 Oct. 2004 and 15 Apr. 2005. These data are presented as an average across N fertility levels. No

interactions were present with N fertility level; therefore, data discussed regarding N fertility have been averaged across all other factors.

Seeding Date

Seeding on 16 August resulted in more rapid establishment of glyphosate-resistant creeping bentgrass compared with later seeding dates (Table 3). Turf cover of plots seeded on 16 August was 1.8-fold greater compared with plots seeded on 1 September when observed on 8 Oct. 2004. Plots seeded on 17 September and 30 September had not progressed enough to make observations on this date.

An interaction between seeding date and mowing regime occurred on 29 Oct. 2004 (Table 2). Plots seeded on 16 August had 2- and 4-fold greater turf cover than plots seeded on 1 September and 17 September when seedlings were initially mowed at 6.4 mm and the mowing height was reduced weekly (mowing regime 1) (Fig. 1). When initial mowing occurred at 6.4 mm and plots were allowed to reach approximately 100% cover before the height of cut was reduced (mowing regime 2), plots seeded on 16 August and 1 September achieved similar cover, 4.4- and 3.5-fold greater than plots seeded on 17 September. Seeding dates of 16 August and 1 September were similar, 3.7- and 3-fold greater than the 17 September seeding date, when mowing was initiated at 12.4 mm and allowed to reach approximately 100% cover before the height of cut was reduced (mowing regime 3) (Fig 1). Plot seeded on 30 September had not progressed enough by 29 October to estimate glyphosate-resistant creeping bentgrass cover.

Interaction between seeding date and mowing regime was also present on 15 Apr. 2005 (Table 2). Regardless of the mowing regime implemented, plots seeded on 30 September produced the lowest turf cover (Fig. 2). When plots were mowed using regime 1,

glyphosate-resistant creeping bentgrass cover decreased approximately 30 percent for every 15 d the seeding date progressed later into the fall. Plots seeded on 16 August and 1 September achieved similar turf cover, at least 1.8-fold greater creeping bentgrass establishment than plots seeded on 17 September when the other two mowing regimes were used (Fig 2).

On 6 May 2005, plots seeded on 16 August, 1 September, and 17 September had turf cover greater than when seeding occurred on 30 September (Table 3). When cover was estimated on 27 May, plots seeded on 16 August had 97% glyphosate-resistant creeping bentgrass cover, while the later seeding dates had cover < 90% and plots were not ready for golf play.

The statistical analysis was based only on glyphosate-resistant creeping bentgrass cover and did not take into account the date putting green height was reached. Plots seeded on 16 August reached final putting green height on 2 Oct. and 22 Oct. 2004 when mowing regimes 1 and 2 were implemented and on 16 May 2005 for mowing regime 3, respectively (Table 1). Only plots mowed using regime 1 reached putting green height in the fall of 2004 when plots were seed on 1 September. Plots seeded on 1 September and maintained using the second mowing regime were mowed at the final height on 30 May 2005 and those of the third mowing regime did not reach the final height of cut. Only plots mowed using regime 1 attained the final height upon completion of the study when seed was sown on 17 September and 30 September (30 May 2005) (Table 1).

In the Midwest, golf course construction projects are often started after Labor Day (approximately 1 September) to avoid interruption to the golf season and minimize revenue loss due to the golf course being closed (Reicher and Hardebeck, 2002). This strategy may prolong the golf season into the fall, but our results indicated that when the conversion process was started on 1 September or later, putting greens were not acceptable for golf play

early the following spring. However, when seeding occurred on 16 August, we found that golf play could be resumed in late fall and putting greens were in excellent condition early the following spring.

These findings are most likely due to the reduction in temperature as seeding moved later into the fall. The optimal seeding date for cool-season turfgrasses is in the late summer when the soil temperature is favorable and the air temperature remains warm enough to allow turfgrass plants to mature (Beard, 1973; Watschke and Schmidt, 1992). Soil temperatures may be warm enough for seed germination, but turf plants are not likely to mature if seeding occurs after 1 September. Juvenile seedlings are more susceptible to the harsh winter climate compared with plants that have matured (Beard, 1973).

Mowing Regime

When glyphosate-resistant creeping bentgrass percentage cover was estimated on 8 Oct. 2004, plots initially mowed at 6.4 mm or 12.7 mm and allowed to reach approximately 100% cover before reducing the mowing height (mowing regimes 2 and 3) achieved turf cover that was similar (Table 4). Turf cover of plots mowed implementing these regimes was 1.3- and 1.2-fold greater than plots mowed at 6.4 mm initially, with the mowing height being reduced immediately (mowing regime 1).

On 29 Oct. 2004, a significant seeding date x mowing interaction occurred (Table 2). No differences were observed among mowing regimes when plots were seeded on 16 August (Fig.1). However, when seeding of glyphosate-resistant creeping bentgrass occurred on 1 September, plots mowed using mowing regime 1 had the lowest cover at 47%, and plots mowed using the other two regimes were similar and achieved turf cover > 70%. Plots seeded on 17 September had not matured adequately to begin implementing the mowing

regimes when turf cover was estimated on 29 Oct. 2004; therefore, no differences were observed (Fig 1).

An interaction between seeding date and mowing regime was also present on 15 Apr. 2005 (Table 2). Turf cover for all mowing regimes was similar when plots were seeded on 16 August (Fig. 2). Plots seeded on 1 September and mowed using regimes 2 and 3 had 90% glyphosate-resistant creeping bentgrass cover, and cover of these plots was 1.3-fold greater than when mowing regime 1 was implemented. Plots seeded on 17 September and mowed using regime 3, achieved 51% turf cover. This was greater than the other mowing regimes, which had similar turf cover. Mowing regime had no effect when seeding of glyphosate-resistant creeping bentgrass took place on 30 September (Fig. 2).

Turfgrass cover on 6 May 2005 was numerically the greatest on plots mowed using regime 3, but not different from plots mowed using regime 2 (Table 4). Mowing regimes 1 and 2 resulted in glyphosate-resistant creeping bentgrass cover that was similar on this date. When plots were observed near the end of the study (27 May 2005), plots mowed by implementing regimes 2 and 3 had similar cover, and the resulting turf cover of was greater than that of plots maintained with mowing regime 1.

Glyphosate-resistant creeping bentgrass establishment was most rapid and the final putting height was reached relatively quickly when mowing was initiated at 6.4 mm and plots were allowed to reach approximately 100% cover before the height of cut was reduced 0.76 mm wk⁻¹ (mowing regime 2) (Table 4 and Figs. 1 and 2). Speed of establishment was reduced compared with the other mowing regimes when mowing was initiated at 6.4 mm and the height of cut was reduced without permitting creeping bentgrass to attain complete cover (mowing regime 1). Although plots mowed for the first time at 12.7 mm, and allowed to attain approximately 100% cover (mowing regime 3) had numerically greater turf cover on several of the observation dates, as the mowing height was reduced we observed significant

scalping of turf. The resulting putting green quality was not acceptable for golf play. Furthermore, when the initial mowing of seedlings was conducted at 12.7 mm, the period of time required to achieve putting green height was considerably longer (Table 1). Only when glyphosate-resistant creeping bentgrass was seeded on 16 August, did plots mowed using regime 3 reach final putting green height (Table 1).

Mowing is a required maintenance practice that is a stress to turfgrass (Beard, 1973). Research has suggested that if turf is managed at a given height, and cut frequently, the stress induced by mowing is minimized (Hull, 1987). However, during putting green conversion and establishment, the height of cut must be reduced; consequently, any stress caused by mowing is magnified. Numerous studies have shown that low mowing heights cause a reduction in creeping bentgrass quality, root biomass and stress tolerance (Salaiz, et al., 1995; Fagerness et al., 2000; Fagerness and Yelverton, 2001). These studies were not conducted during bentgrass establishment, but it is possible that any strain applied to the turf plant would hinder its ability to spread and cover the intended area. We observed that reduction in the mowing height during establishment compromised putting green quality and slowed turfgrass cover, most notably with the later seeding dates.

Researchers studying creeping bentgrass, perennial ryegrass (*Lolium perenne* L.), and Kentucky bluegrass (*Poa pratensis* L.) have found that lower mowing heights increase tiller production and shoot density (Krans and Beard, 1975; Lush and Rogers, 1992; Fagerness et al., 2000). Moderately low mowing encourages stolon production, but when the height of cut is extremely short, stolon initiation can be reduced (Beard, 1973).

The solution to mowing strategy during the conversion of putting greens to glyphosate-resistant creeping bentgrass is to mow at a height that does not strain seedlings while mowing low enough to increase shoot density and stolon production. The results of this experiment indicate that that the initial mowing should be conducted at 6.4 mm and

maintained at this height until approximately full turfgrass cover is reached. This height of cut promotes the spread of creeping bentgrass and minimizes mowing stress. Full cover was attained relatively quickly when the initial mowing height was 12.7 mm, but as the height of cut was reduced considerable scalping was observed and turf quality was compromised. When mowing is initiated at heights too distant from the projected height, extreme defoliation occurs as the mowing height is reduced. This stress is more detrimental to establishment than when seedlings are initially mowed closer to the soil surface (Beard, 1973). Therefore, Beard (1973) suggests that the initial mowing should occur when seedlings reach a height one-third greater than the height at which turfgrass will be maintained.

Nitrogen Fertility

No differences were observed between N fertility levels on 8 Oct. or 29 Oct. 2004 (Tables 2 and 5). On 15 Apr., 6 May, and 27 May 2005 plots fertilized with N at 2.44 g m⁻² had 2, 2, and 1% greater cover, respectively (Table 4). Although there were differences, the increase in cover produced by the higher N level was not great enough to make a practical recommendation.

This study was conducted on a native-soil putting green and may have reduced the effect of N fertility. Differences may have been more pronounced had the study taken place on a sand-based putting green with little or no organic matter. Additionally, the two rates used (1.2 and 2.44 g m⁻² wk⁻¹) may have been too similar, therefore resulting in a small effect. White (2003) recommends N be applied on a 5-d interval at 1.46 to 2.92 g m⁻² for creeping bentgrass establishment. In contrast, Beard (2002) suggests using the same rate on a 7- to 10-d interval. The importance of N fertilization during establishment should not be underestimated based on our results and future research should be conducted using a wider

range of N levels (2.44 verses 4.88 verses 7.32 g m⁻² wk⁻¹) applied at differing intervals (5- verses 7- verses 10-d intervals).

Conclusion

Our results indicate that it is possible to convert a previously established putting green to glyphosate-resistant creeping bentgrass with minimal interruption to golf play. When seeding occurred in late summer (16 August), glyphosate-resistant creeping bentgrass was mowed at putting green height late in the fall and golf play could have been resumed approximately 7- to 10-wk after seeding. We found that when glyphosate-resistant creeping bentgrass seedlings were initially mowed at 6.4 mm and the putting green was allowed to achieve approximately full cover before the height of cut was lowered by 0.76 mm wk⁻¹, complete turf cover was achieved rapidly and putting green quality was maintained. However, this is a guideline. The mowing strategy should be adjusted based on weather conditions during conversion and progress of establishment. We did not observe any differences in establishment in response to N fertility level, but it is possible that higher N levels and shorter application intervals may hasten glyphosate-resistant creeping bentgrass establishment.

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Table 1. Mowing height schedule used to convert a native-soil putting green from ‘Crenshaw’ creeping bentgrass to glyphosate-resistant creeping bentgrass in 2004.

Seeding date Mowing regime	Time (date)		
	Initial mowing	First mowing height reduction	Final mowing height [†]
16 Aug.			
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹	26 Aug. 2004	3 Sept. 2004	2 Oct. 2004
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	26 Aug. 2004	24 Sept. 2004	22 Oct. 2004
Initiate mowing at 12.7 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	30 Aug. 2004	24 Sept. 2004	16 May 2005
1 Sept.			
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹	17 Sept. 2004	24 Sept. 2004	22 Oct. 2004
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	17 Sept. 2004	29 Apr. 2005	30 May 2005
Initiate mowing at 12.7 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	8 Oct. 2004	29 Apr. 2005	----‡
17 Sept.			
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹	22 Apr. 2005	29 Apr. 2005	30 May 2005
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	22 Apr. 2005	----‡	----‡
Initiate mowing at 12.7 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	22 Apr. 2005	----‡	----‡
30 Sept.			
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹	22 Apr. 2005	29 Apr. 2005	30 May 2005
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	22 Apr. 2005	----‡	----‡
Initiate mowing at 12.7 mm, reduce height of cut 0.76 mm wk ⁻¹ after ≈ 100% turf cover was achieved	22 Apr. 2005	----‡	----‡

[†]Final mowing height of the putting green was 3.3 mm.

[‡]Plots did not reach final mowing height upon termination of the experiment.

Table 2. Analysis of variance for effect of seeding date, mowing regime, and nitrogen fertility on conversion of a native-soil putting green previously established to ‘Crenshaw’ creeping bentgrass to glyphosate-tolerant creeping bentgrass. Glyphosate was applied at 1.26 kg a.e. ha⁻¹ to existing turf 1 d before seeding. Glyphosate-tolerant creeping bentgrass was seeded on 16 Aug., 1 Sept., 17 Sept., and 30 Sept. 2004 at 7.3 g m⁻².

Source of variation	Date of observation				
	2004		2005		
	8 Oct.	29 Oct.	15 Apr.	6 May	27 May
	F-ratio				
Seeding Date (D)	120.10 ^{**}	106.86 ^{**}	146.39 ^{**}	43.76 ^{**}	16.47 ^{**}
Mowing regime (M)	61.58 ^{**}	22.97 ^{**}	5.61 [*]	8.42 ^{**}	8.29 ^{**}
Nitrogen fertility (N)	1.01 ^{NS}	22.02 ^{NS}	10.82 ^{**}	10.26 ^{**}	6.55 [*]
D x M	3.32 ^{NS}	22.27 ^{**}	4.33 ^{**}	2.71 ^{NS}	2.17 ^{NS}
D x N	0.25 ^{NS}	4.91 ^{NS}	2.90 ^{NS}	1.63 ^{NS}	1.16 ^{NS}
M x N	0.37 ^{NS}	0.43 ^{NS}	2.70 ^{NS}	1.81 ^{NS}	0.62 ^{NS}
D x M x N	0.07 ^{NS}	2.9 ^{NS}	0.49 ^{NS}	0.33 ^{NS}	0.14 ^{NS}

^{*}, ^{**}, and ^{NS} indicate significance at $P = 0.05$, $P = 0.01$, and not significant, respectively.

Table 3. Percentage cover of glyphosate-resistant creeping bentgrass for each seeding date investigated to convert a native-soil putting green from ‘Crenshaw’ creeping bentgrass to glyphosate-resistant creeping bentgrass in 2004. Glyphosate was applied 1 d before each respective seeding date and plots were seeded at 7.3 g m⁻². Values are means from three replications averaged across all other factors investigated in the study.

Seeding date	Time (date of observation)		
	2004	2005	
	8 Oct	6 May	27 May
	%		
16 Aug.	93 a [†]	96 a	97 a
1 Sept.	56 b	85 a	88 a
17 Sept.	---- [‡]	55 b	77 a
30 Sept.	---- [‡]	21 c	45 b
LSD (0.05)	20	25	28

[†]Values within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher’s F -protected least significant difference test.

[‡]Percentage cover of glyphosate-resistant creeping bentgrass was not sufficient enough to accurately estimate.

Table 4. Percentage glyphosate-resistant creeping bentgrass cover for each mowing regime investigated to convert a native-soil putting green from ‘Crenshaw’ creeping bentgrass to glyphosate-resistant creeping bentgrass in 2004. Glyphosate was applied 1 d before each respective seeding date and plots were seeded at 7.3 g m^{-2} . Values are means from three replications averaged across all other factors investigated in the study.

Mowing regime	Time (date of observation)		
	2004	2005	
	8 Oct	6 May	27 May
	%		
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹	64 b [†]	60 b	72 a
Initiate mowing at 6.4 mm, reduce height of cut 0.76 mm wk ⁻¹ after $\approx 100\%$ turf cover was achieved	77 a	65 ab	79 a
Initiate mowing at 12.7 mm, reduce height of cut 0.76 mm wk ⁻¹ after $\approx 100\%$ turf cover was achieved	82 a	68 a	80 a
LSD (0.05)	6	6	7

[†]Values within a column followed by the same letter are not significantly different at $P \leq 0.05$ according to Fisher’s *F*-protected least significant difference test.

Table 5. Percentage cover of glyphosate-resistant creeping bentgrass for each N fertility level used to convert a native-soil putting green from ‘Crenshaw’ creeping bentgrass to glyphosate-resistant creeping bentgrass in 2004. Glyphosate was applied 1 d before each respective seeding date and plots were seeded at 7.3 g m^{-2} . Values are means from three replications averaged across all other factors investigated in the study.

N fertility level g m ⁻²	Time (date of observation)				
	2004		2005		
	8 Oct	29 Oct	15 Apr	6 May	27 May
1.2	75 ^{NS}	61 ^{NS}	57 ^{**}	63 ^{**}	76 [*]
2.4	74	62	59	65	77

^{*}, ^{**}, and ^{NS} indicate significance within a column at $P = 0.05$, $P = 0.01$, and not significant, respectively.

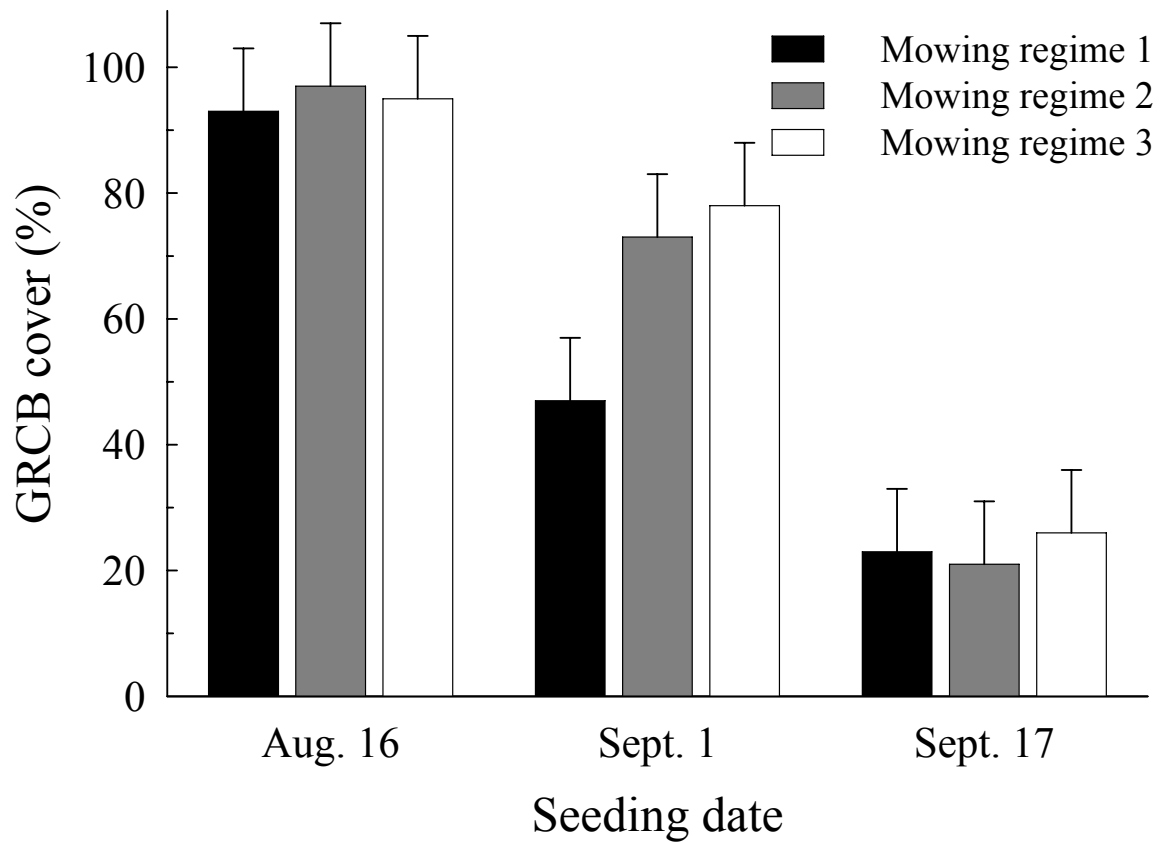


Fig. 1. Percentage cover of glyphosate-resistant creeping bentgrass (GRCB) estimated on 29 Oct. 2004 on a native-soil putting green converted from 'Crenshaw' creeping bentgrass to glyphosate-resistant creeping bentgrass. Glyphosate was applied 1 d before each respective seeding date and plots were seeded at 7.3 g m^{-2} . Values are means from three replications, averaged across N fertility level main effects. Error bars depict Fisher's *F*-protected LSD calculated at the $P \leq 0.05$ level and should be used to make comparisons among mowing regimes within each seeding date. Fisher's *F*-protected LSD ($P \leq 0.05$) to make comparisons among seeding date within each mowing regime = 30.

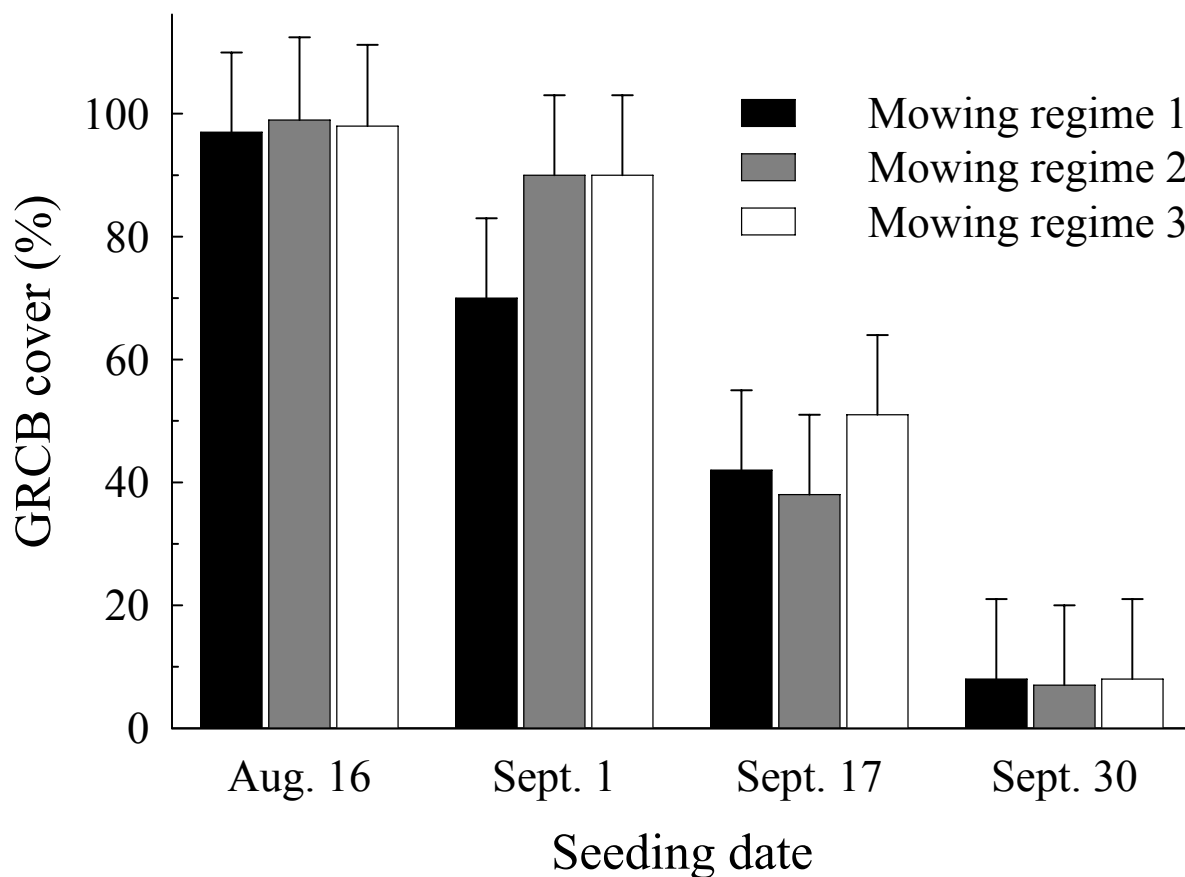


Fig. 2. Percentage glyphosate-resistant creeping bentgrass (GRCB) cover estimated on 15 Apr. 2005 on a native-soil putting green converted from 'Crenshaw' creeping bentgrass to glyphosate-resistant creeping bentgrass. Glyphosate was applied 1 d before each respective seeding date and plots were seeded at 7.3 g m^{-2} . Values are means from three replications, averaged across N fertility level main effects. Error bars depict Fisher's *F*-protected LSD calculated at the $P \leq 0.05$ level and should be used to make comparisons between mowing regimes within each seeding date. Fisher's *F*-protected LSD ($P \leq 0.05$) to make comparisons between seeding date within each mowing regime = 20.

GENERAL CONCLUSION

Glyphosate Application Timing

The ability of the existing turf to compete with glyphosate-resistant creeping bentgrass seedlings was evident. In fairway turf of creeping bentgrass, Kentucky bluegrass, and perennial ryegrass and putting green turf of creeping bentgrass, establishment was reduced because of competition from existing turf. During conversion of golf course turf to glyphosate-resistant creeping bentgrass, glyphosate must be applied near the time of seeding to remove competition from existing turf. These findings are consistent with others conducting similar studies (Gaussoin and Branham, 1989; Cattani, 2001; Kendrick and Danneberger, 2002; Reicher and Hardebeck, 2002).

Surface Preparation

Large soil openings produced by core aeration and vertical mowing resulted in a successful conversion of fairway height turf to glyphosate-resistant creeping bentgrass. On golf course fairways, surface disruption can be tolerated to a greater extent than on putting greens. Alternate equipment that results in less damage to the putting green surface may allow for faster return to conditions acceptable for golf play. Although we did not find any difference in the method of surface preparation, we did observe that preparing the surface with core aeration and vertical mowing resulted in more surface disruption and required more labor than the alternate methods used.

Seeding Rate

Higher-than-normal seeding rates are sometimes used to increase speed of turfgrass establishment, especially during conversion when it is likely that seeds will not enter an

environment conducive for germination. For initial establishment of creeping bentgrass, Beard (1973) recommends seeding at 2.4 to 4.9 g m⁻². We found that seeding at 7.3 or 12.2 g m⁻² rather than 2.4 g m⁻² provided the quickest conversion of a previously established putting green to glyphosate-resistant creeping bentgrass. The use of the highest rate is not recommended because other research has shown that seeding rates too high can hamper seedling development and increase disease incidence (Madison, 1966; Rossi and Millett, 1996).

Seeding Date

The golf season reaches its peak during the summer months and play generally begins to reduce near Labor Day. Projects that require the closure of golf courses are often started after Labor Day (Reicher and Hardebeck, 2002). Golf play may be greater during mid-August than after Labor Day, but our results indicate that seeding in mid-August would likely allow for golf play to resume late in the fall. When seeding occurred after Labor Day, satisfactory establishment was not obtained until approximately 1 June of the following spring.

Mowing Regime

Glyphosate-resistant creeping bentgrass establishment was most rapid when the seedlings were initially mowed at 6.4 mm and the putting green was allowed to reach full cover before the height of cut was reduced 0.76 mm wk⁻¹. This mowing height also allowed turfgrass to be mowed at putting green height relatively quickly. Seedlings mowed initially at 12.7 mm were scalped as the mowing height was reduced, resulting in poor putting green quality. Glyphosate-resistant creeping bentgrass establishment was slowed when the putting green was not allowed to achieve full cover before the height of cut was reduced.

Nitrogen fertility

Our results indicate that the glyphosate-resistant creeping bentgrass establishment was not increased by the application of N at 1.2- versus 2.44-g m⁻². These two levels of fertility may have been too similar to see marked differences. Additionally, (White) 2003 suggests that N applied on a more frequent basis speeds establishment. More research should be conducted investigating a wider range of N fertility levels at differing application intervals.

Summary

Conversion of golf course turf to glyphosate-resistant creeping bentgrass is an option that many turfgrass managers may consider, but closing a golf course for a long period of time to conduct the conversion may not be acceptable. This research demonstrates that a successful conversion of golf course turf to glyphosate-resistant creeping bentgrass can occur with minimal interruption to golf play.

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