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

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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 aerification 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 dominate 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 aerification 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/seeder™ 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 ≥ 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/seeder™, 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 aerification 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/seeder™ 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 aerification 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.

References

Beard, J.B. 1973. Turfgrass: Science and culture. Prentice-Hall, Englewood Cliffs, NJ.

Beard, J.B. 2002. Turf management for golf courses. 2nd ed. Ann Arbor Press, Chelsea, MI.

Cattani, D.J. 2001. Effect of turf competition on creeping bentgrass seedling establishment. Int. Turfgrass Soc. Res. J. 9:850-854.

Christians, N.E. 1996. A historical perspective of annual bluegrass control. Golf Course Manage. 64(11):49-57.

Dant L.A., and N.E. Christians. 2005. Timing of Roundup application critical when converting golf course turf to Roundup Ready creeping bentgrass. Int. Turfgrass Soc. Res. J. *In press*.

Fry, J.D. and J.D. Butler. 1989. Annual bluegrass and creeping bentgrass evapotranspiration rates. HortScience 24:269-271.

Gaussoin, R.E. and B.E. Branham. 1989. Influence of cultural factors on species dominance in a mixed stand of annual bluegrass/creeping bentgrass. Crop Sci. 29:480-484.

Kendrick, D.L. and T.K. Danneberger. 2002. Lack of competitive success of an intraseeded creeping bentgrass cultivar into an established putting green. Crop Sci. 42:1615-1620.

Kraft, R.W., S.J. Keeley, and K. Su. 2004. Conversion of fairway-height perennial ryegrass turf to Kentucky bluegrass without nonselective herbicides. Agron. J. 96:576-579.

Little, T.M. and F.J. Hills. 1972. Statistical methods in agricultural research. Univ. of California, Davis, Davis, CA.

Lush, W.M. 1989. Adaptation and differentiation of golf course populations of annual bluegrass (*Poa annua*). Weed Sci. 37:54-59.

Madison, J.H. 1966. Optimum rates of seeding turfgrasses. Agron. J. 58:441-443.

Reicher, Z.J. and G.A. Hardebeck. 2002. Overseeding strategies for converting golf course fairways to creeping bentgrass. HortScience 37:508-510.

SAS Institute. 1999-2001. Software release 8.02. SAS Inst., Cary, NC.

Turner, T.R. and N.W. Hummel, Jr. 1992. Nutritional requirements and fertilization. p. 385-439. *In* D.V. Waddington et al. (eds.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Vargas, J.M., Jr. and A.J. Turgeon. 2004. *Poa annua*: Physiology, culture and control of annual bluegrass. John Wiley and Sons, Hoboken, NJ.

Watschke, T.L. and R.E. Schmidt. 1992. Ecological aspects of turf communities. p. 129-174. *In* D.V. Waddington et al. (eds.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

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/seeder™	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}.

	Time after seeding (weeks)			
	3	5	7	10
Source of variation	*F*-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 aerification 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/seeder™				
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}.

	Time after first seeding (weeks)†			
	33	35	37	39
Source of variation	*F*-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)[†]			
Seeding date	33	35	37	39
	%			
Bare soil[‡]				
19 Aug.	98[§]	98	100	100
9 Sept.	80	87	90	89
30 Sept.	48	55	55	58
Core aerification 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.

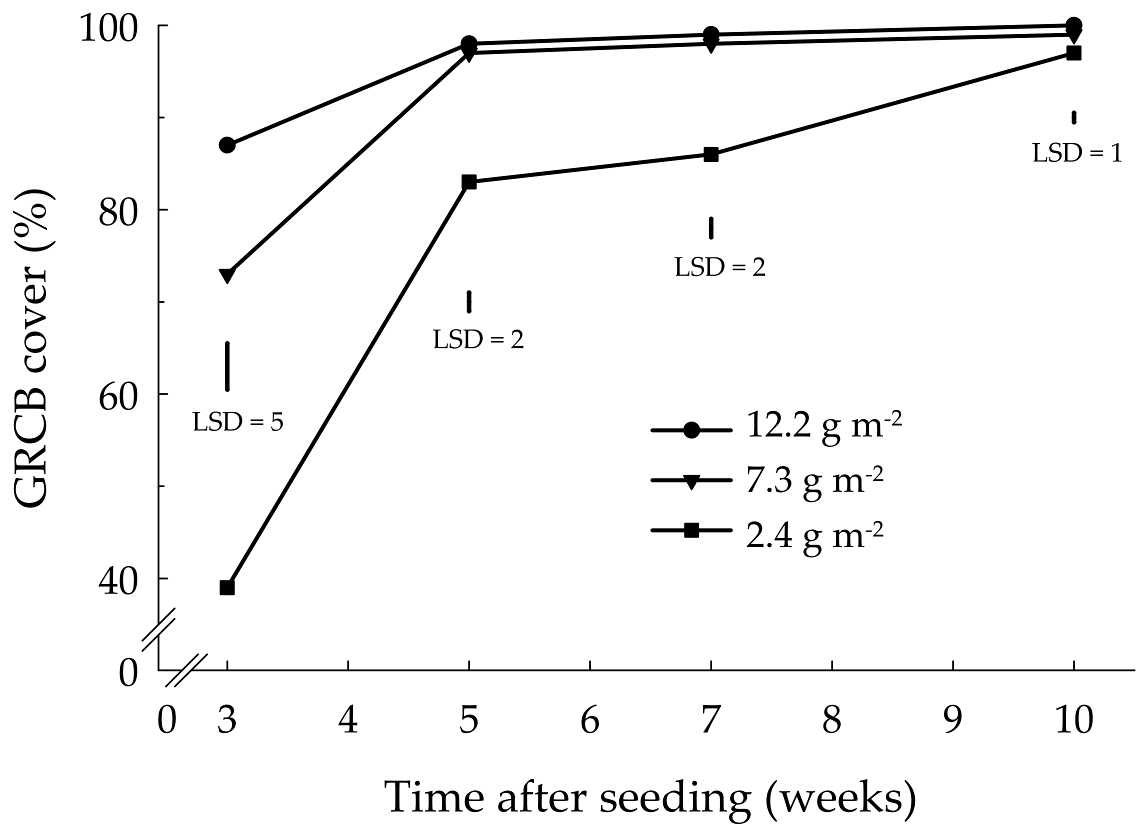

Figure 1. Greater seeding rates resulted in a more rapid conversion to glyphosate-resistant creeping bentgrass (GRCB) than lower seeding rates on a native-soil putting green previously established to 'Penncross' creeping bentgrass. Glyphosate was applied to existing turf on 18 Aug. 2003 at 1.26 kg a.e. 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 $P \leq 0.05$.

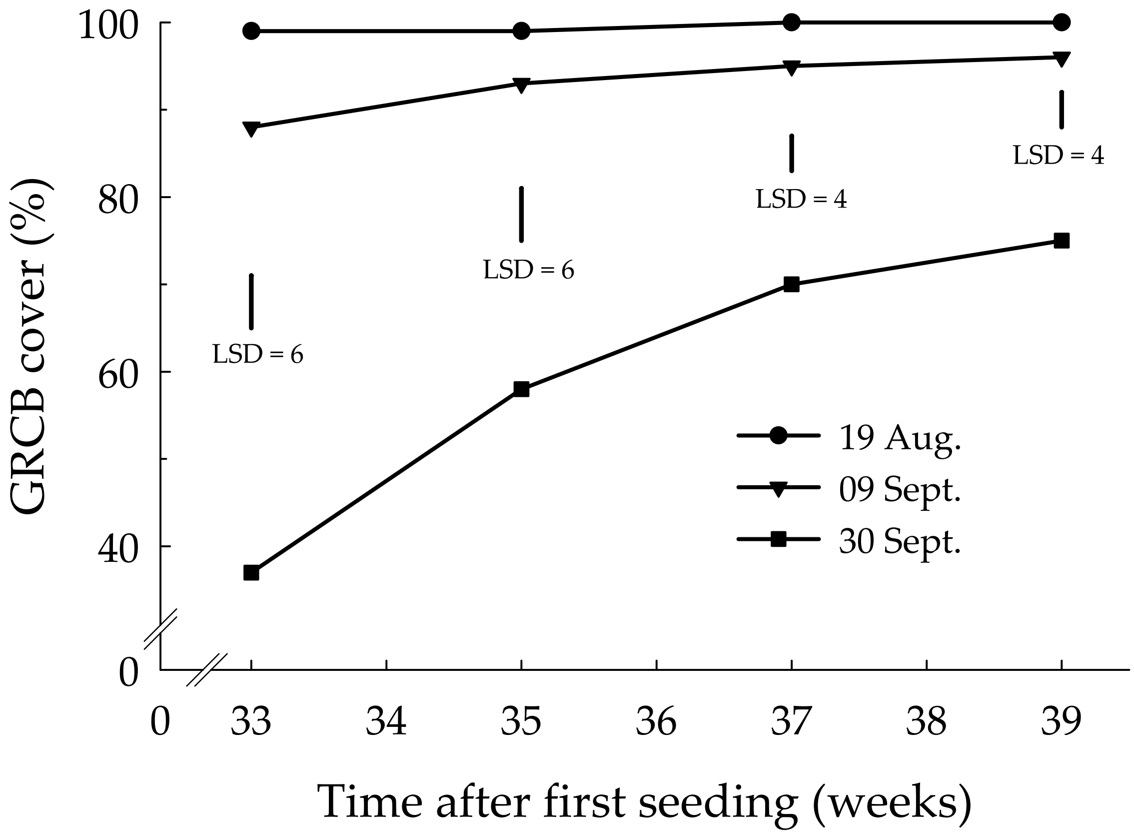

Figure 2. Earlier seeding dates resulted in greater glyphosate-resistant creeping bentgrass (GRCB) cover than did later dates on a native-soil putting green previously established to 'Penncross' creeping bentgrass. Glyphosate-resistant creeping bentgrass was seeded at 7.3 g m^{-2} on 19 Aug., 9 Sept., 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 $P \leq 0.05$.