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A Guide to Establishing Seeded Zoysiagrass in the Transition Zone

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Introduction

Zoysiagrass (*Zoysia japonica* Steud.) is a warm-season turfgrass species that provides an excellent golfing surface in the transition zone of the US that can be used for tees, fairways, roughs, and bunker faces. Established zoysiagrass creates a uniform, dense, low-growing, high-quality turf with excellent heat, drought, pest, and wear tolerance compared to cool-season grasses, resulting in fewer inputs and lower maintenance costs (3,12).

Zoysiagrass was first introduced by seed in the US around 1900 (23), but was not used on golf courses until the 1950s when the cultivar Meyer was released (15). Meyer zoysiagrass gained immediate popularity because of its heat, freeze, and drought tolerance in the transition zone (14). Although zoysiagrass use was increasing in the US, Meyer could only be established vegetatively because its seed did not produce plants with the same texture, vigor, and freeze tolerance (16). Establishing zoysiagrass by strip-sodding, sprigging, or plugging is less expensive than solid-sodding, but these methods may require two or more years to achieve full establishment (31). As a result, the high cost of vegetative establishment and a slow establishment rate have limited widespread use of Meyer. Several improved vegetative cultivars of zoysiagrass are currently being tested, but the winter hardiness of these cultivars is yet to be proven and Meyer remains the most widely-used cultivar in the transition zone (9).

Historically, seeded zoysiagrass had limited use because of poor turf quality, germination rates, and seed production (35,37). Korean common and Chinese common are two seeded varieties harvested from native stands in Korea or China that have been available for many years. However, these varieties have a coarse leaf texture and produce lower quality turfs compared to Meyer (24,25). Additionally, zoysiagrass seed has a dormancy factor that results in low germination rates. Treatments to overcome seed dormancy were discovered in the 1980s (31,37,38). The germination rate of untreated dormant zoysiagrass seed is < 10% while seed chemically scarified with potassium hydroxide has germination rates as high as 90% (31). A final problem limiting zoysiagrass establishment by seed and the number of cultivars released is low seed yields (~100 lb/acre) of experimental cultivars (35). However, cultivars that can be established by seed with similar quality to Meyer are now commercially available (Table 1) (25).

Table 1. Commercially available zoysiagrass cultivars.

Cultivar	Sponsor	Commercially available
Companion[y]	Seed Research of Oregon	yes
Zenith[yz]	Patten Seed Company	yes
J-36[z]	Simplot Turf & Horticulture/Jacklin Seed	seed samples only
J-37[yz]	Simplot Turf & Horticulture/Jacklin Seed	seed samples only

[y] Entered in 2002 NTEP Zoysiagrass Test.

[z] Entered in 1996 NTEP Zoysiagrass Test.

Seeded zoysiagrass has tremendous potential for golf courses use because it affords the benefits of vegetatively established zoysiagrass, but can be established at a fraction of the cost of sodded zoysiagrass. Today, all commercially available zoysiagrass seeds are chemically scarified to improve germination rates and the feasibility of using seed on a large scale. However, there was a limited body of information regarding establishing zoysiagrass from seed. This paper summarizes recent research in the transition zone on establishing zoysiagrass by seed and can be used as a guide by practitioners wishing to establish seeded zoysiagrass.

Site Preparation

There are two practical scenarios for establishing seeded zoysiagrass, the first of which is planting on bare soil where there is no existing vegetation to remove prior to establishment. This is usually the case during the construction of a new golf course or teeing ground. A second scenario is preparation of a seedbed in an established cool-season turf, which provides more options during the renovation process. Regardless of site preparation, most zoysiagrass cultivars prefer slightly acid soils with pH from 4.5 to 6.0 (26), though Meyer grows best in soil with pH ranging from 6.0 to 7.0 (20).

Before seeding into bare or fallow ground, perennial grassy weeds should be controlled with glyphosate (N-(phosphonomethyl)glycine) prior to tilling since there are few selective herbicides that control perennial grassy weeds in zoysiagrass with a single application. Maximize seed-to-soil contact after seeding, but do not bury the seeds deeper than 1/4 inch deep since zoysiagrass seed requires light to germinate (10). Zoysiagrass establishes most quickly when the soil is tilled prior to seeding and can produce 100% cover by the end of the growing season when there is no weed pressure (Fig. 1) (29).

Fig. 1. 'Zenith' zoysiagrass established in a seedbed that was tilled and fumigated with methyl bromide prior to seeding. Zoysiagrass coverage 15 days after seeding (A), 45 days after seeding (B), and 90 days after seeding (C).

There are three approaches to successfully establishing seeded zoysiagrass into an existing stand of cool-season turfgrass such as perennial ryegrass. The first option is to remove all competition prior to seeding by killing the existing turf with glyphosate, followed by aerification and verticutting prior to seeding. Using this option, researchers have achieved 84% or more zoysiagrass coverage prior to winter if seeded in early summer and herbicides are applied to control annual grassy and broadleaf weeds (28,42). Although this method is disruptive and would likely require that the area be closed during establishment, it is more effective and speeds establishment compared to the following two methods.

A second option for converting a cool-season fairway to zoysiagrass without closing the area is to use a strip-seeding technique (42), which is analogous to strip-sodding. Zuk and Fry (42) found that over 52% zoysiagrass coverage occurred in a perennial ryegrass sward after two years, and over 73% after three years when 3-inch wide strips, 13 inches apart, were treated with glyphosate and seeded to 'Zenith' zoysiagrass (Fig. 2). The main advantage to this technique is that the entire sward is not disrupted. Play can continue from the cool-season turf during establishment, allowing courses to remain open and avoid revenue losses. This method also requires less seed resulting in a lower establishment cost (42). Anticipating that this method may be desirable for establishing zoysiagrass, equipment was developed and tested and a patent is pending (13). The disadvantage to this method is that it could take at least four years to convert a fairway from perennial ryegrass to 90% zoysiagrass coverage (42). Applying a herbicide such as pronamide (3,5-dichloro (N-1,1-dimethyl-2-propynyl)benzamide) or foramsulfuron (1-(4,6-dimethoxypyrimidin-2-yl)-3-[2-(dimethylcarbamoyl)-5-formamidophenylsulfonyl]urea) to control perennial ryegrass (39) after the second season will reduce competition and could hasten zoysiagrass establishment. Alternatively, glyphosate could be applied in colder climates in late winter to eradicate remaining cool-season turfgrasses from dormant zoysiagrass (36).

Fig. 2. 'Zenith' zoysiagrass coverage two full seasons after strip seeding 3-inch wide rows, 13 inches apart into a perennial ryegrass turf. This picture was taken when zoysiagrass was dormant (straw brown color).

A third method for establishing seeded zoysiagrass involves use of a reel mower to scalp and weaken the existing cool-season turf prior to seeding. This method is less successful than strip-seeding or broadcast applications of glyphosate but did result in 40 to 75% zoysiagrass coverage three years after planting in a perennial ryegrass sward (42). Existing perennial ryegrass turf is scalped at 0.25 inch three times weekly after seeding until zoysiagrass begins tillering, which occurs about 50 days after seeding depending upon location and site conditions (42). Scalping reduces perennial ryegrass competition during zoysiagrass establishment but allows golf to continue. Like the previous strip-seeding method, this method will require at least four years to obtain 90% or more zoysiagrass coverage. Similar herbicide strategies as outlined for the strip-seeding method could be used to eradicate cool-season grasses two to four years after planting.

Establishing seeded zoysiagrass in an existing perennial ryegrass fairway without glyphosate or scalping treatments prior to seeding has been unsuccessful (28,42). Additionally, plant growth regulators applied to perennial ryegrass prior to interseeding zoysiagrass did not suppress perennial ryegrass enough to allow seedlings to emerge and compete with existing turf (42). Interseeding zoysiagrass directly into perennial ryegrass was unsuccessful likely due to decreased light penetration and soil temperatures at the base of the canopy, reduced seed to soil contact, increased plant competition, and allelopathic effects from perennial ryegrass (41,42,43). Therefore, eradicating existing turf with glyphosate prior to seeding is essential for rapid zoysiagrass establishment.

Seeding Date

Late spring to early summer is the preferred seeding date for warm-season grasses (18). Zoysiagrass can be seeded when soil surface temperatures first reach 68 to 72°F (8,32). This timing allows for the longest period of warm temperatures necessary to adequately establish zoysiagrass before winter (3). Germination typically occurs 10 or more days after seeding, but may occur in as little as 7 days under optimum soil moisture and temperature. Due to the slow establishment of zoysiagrass, the seeding window for acceptable establishment is narrow. Korean common zoysiagrass seeded on 18 June or 1 July in southern Illinois provided up to 90% coverage by October (31). Seeding Zenith zoysiagrass in June in Kansas produced 75% or more coverage before winter (42). Zenith seeded between 1 and 15 June in Indiana and 1 June to 1 July in Kentucky produced 90% or more coverage by October (29).

A growing degree day (GDD) model was applied to the establishment of zoysiagrass and used to predict the latest possible seeding date at various locations in the transition zone. Using the formula GDD = [(Max. Temp.°C + Min. Temp.°C)/2] - 5°C, it was found that at least 1750 accumulated growing degree days prior to 1 October were required to achieve 95% or more zoysiagrass coverage in Indiana and Kentucky (29). Using this growing degree model and

30-year normal weather data, zoysiagrass could be seeded as late as 21 June in West Lafayette, IN (north of the transition zone); 28 June in Washington, DC; 30 June in Manhattan, Kansas; 1 July in Louisville, KY; 1 July in Fayetteville, AR; 3 July in Nashville, TN; and 4 July in St. Louis, MO and still achieve 95% or more coverage prior to winter (Fig. 3). Overall, data suggest that the seeding window for zoysiagrass is 1 June to 1 July throughout most of the transition zone. It is important to seed as early as possible within this window to allow ample time for the stand to mature in case of weed competition, drought or cooler-than-average temperatures, all of which will reduce establishment rates. Zoysiagrass has been successfully established when seeded in May (27). However, seeding zoysiagrass before 1 June may reduce initial germination and establishment rates due to cooler air and soil temperatures, and could increase competition from germinating annual bluegrass (*Poa annua* L.) during cool, wet springs. Seeding zoysiagrass too late in summer reduces coverage prior to winter, but has little effect on low temperature injury in Indiana and Kentucky (29). However, seedlings may be more prone to winter desiccation during dry winters with no snow cover.

Fig. 3. A growing degree day (GDD = [(Max. Temp. °C + Min. Temp. °C)/2] - 5 °C) model was applied to the establishment of 'Zenith' zoysiagrass in the transition zone and it was found that at least 1750 accumulated growing degree days prior to 1 October were required to establish 95% or more zoysiagrass. Using this growing degree model and 30-year normal weather data, zoysiagrass could be seeded as late as 21 June in West Lafayette, IN (north of the transition zone); 28 June in Washington, DC; 30 June in Manhattan, KS; 1 July in Louisville, KY; 1 July in Fayetteville, AR; 3 July in Nashville, TN; and 4 July in St. Louis, MO and still produce 95% or more coverage.

Seeding Rate

When seeding Korean common zoysiagrass in Illinois, Portz et al. (31) recommended seeding at 1.0 to 2.0 lb/1000 ft^2, which was supported by Landry and Choi (21) who found 2.0 lb/1000 ft^2 produced the highest shoot and root growth in the greenhouse. However, Maki et al. (22) suggested the optimum seeding rate is closer to 3.1 lb/1000 ft^2. A range of seeding rates was evaluated by Patton et al. (29) using Zenith zoysiagrass. Rates as high as 6.0 lb pure live seed (PLS) per 1000 ft^2 were assessed, but there was no advantage to seeding more than 2.0 lb PLS per 1000 ft^2 when evaluated 42 days after seeding (29).

Additionally, zoysiagrass is more susceptible to drought stress when seeded at higher rates (6). For rapid establishment, 1.0 to 2.0 lb PLS per 1000 ft^2 are recommended, whereas 0.5 lb PLS per 1000 ft^2 is recommended to reduce cost in areas where rapid coverage is not required (Fig. 4) (29). Additional research demonstrated that coverage after one growing season was increased by a maximum of 11% when seeding rates were increased from 1.0 to 2.0 lb PLS per 1000 ft^2 (28). However, the estimated cost of increasing the seeding rate from 1.0 to 2.0 lb PLS per 1000 ft^2 is $900/acre, which raises the question of whether the improvement in zoysiagrass coverage is economically justified (28).

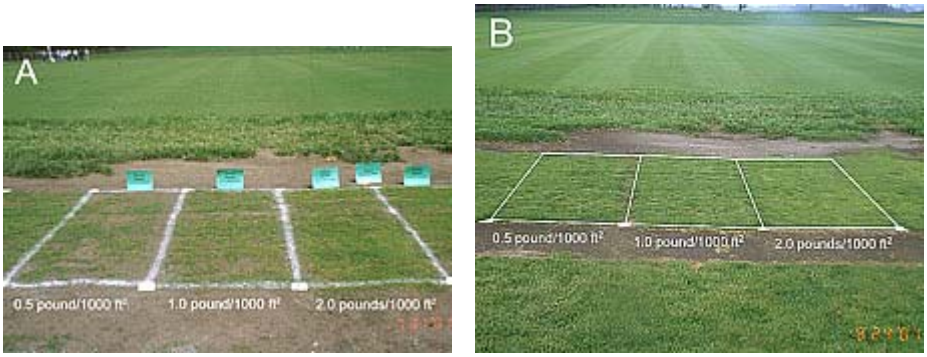

Fig. 4. 'Zenith' zoysiagrass established at different seeding rates in a seedbed that was tilled and fumigated with methyl bromide prior to seeding. Zoysiagrass establishment 39 (A) and 94 (B) days after seeding when seeded at 0.5, 1.0 and 2.0 lb pure live seed per 1000 ft^2.

Seed Covers

Covers are often used on northern golf courses to protect greens during the winter, but they can also be used for soil warming. It is known that zoysiagrass germination increases as temperatures rise, with maximum germination occurring between 86 to 95°F (31,43). The first report of using covers to establish zoysiagrass was in 1967. Yu and Yeam (40) doubled the germination rate of zoysiagrass seed by using a polyethylene film, whereas Portz et al. (32) found that clear polyethylene covers placed over the seedbed for 7 or 14 days after seeding increased germination and zoysiagrass coverage in Illinois and Maryland. Although soil surface temperatures rose as high as 133°F under these covers, zoysiagrass germination is not inhibited until soil temperatures exceed 140°F (32). However, seedlings can be killed or injured at temperatures above 122°F, indicating that the timing of polyethylene cover removal is important (22). Maki et al. (22) recommended that covers be left on for two to three weeks after seeding. These studies indicate that polyethylene covers can be used to increase germination and early establishment without damaging seedlings if removed no later than two weeks after seeding. Other materials tested such as straw (80 lb/1000 ft^2), did not enhance germination because they excluded light and reduced soil temperatures (32). Organic fiber mats increased establishment when used in non-irrigated areas likely due to increased soil moisture but did not increase establishment when used in irrigated plots (17). Anecdotal evidence suggest that porous germination blankets, such as those used by Patton et al. (29), could also be useful for increasing zoysiagrass germination and coverage. Seed germination blankets allow light penetration and gas exchange, facilitate soil warming, increase soil moisture holding capacity, and can be used without the risk of excessive temperature build-up. Regardless of the type of cover, covers should be removed two weeks after seeding to increase germination without risking injury to seedlings.

Post-Seeding Weed Control

Effective weed control is critical when seeding zoysiagrass in non-fumigated soil because of its slow germination and growth rate and because its optimum seeding period coincides with the germination of summer annual grassy weeds. Zoysiagrass establishment by seed can be significantly reduced if perennial weeds are not completely controlled before renovation and summer annual

weeds are not controlled after seeding (28). Though weed species and pressure vary among sites, weeds that commonly reduce zoysiagrass establishment include cool-season grasses such as perennial ryegrass and annual bluegrass, and warm-season grasses such as bermudagrass (*Cynodon* spp.), crabgrass (*Digitaria spp.*), and goosegrass (*Eleusine indica* L. Gaertn.).

Many herbicides are labeled for weed control in established zoysiagrass, but currently only carfentrazone (X,2-dichloro-5-[4-(difluromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]-4-fluorobenzenepropanic acid) and quinclorac (3,7-dichloro-8-quinolinecarboxylic acid) are labeled for use on zoysiagrass seedlings (1,2). Researchers have realized the need for studies evaluating the safety of herbicides on zoysiagrass seedlings and papers have recently been published on this topic. Herbicide applications are based on the date emergence occurs. Researchers working with weed control in seedling zoysiagrass have defined emergence as a uniform stand of one-leaf seedlings about 0.5 inch tall (28,29) which typically occurs 19 to 21 days after seeding, but can occur later if seeded when soil and air temperatures are still cool (28,29), or soil moisture is limiting (Fig. 5). Table 2 summarizes the results of research evaluating the safety of herbicide applications timed according to zoysiagrass seedling emergence on either Korean common or Zenith. There are reports of differences in herbicide tolerance among vegetatively established cultivars (19), but it is not known whether seeded cultivars like Companion, J-36, and J-37 will tolerate herbicides differently than Zenith and Korean common.

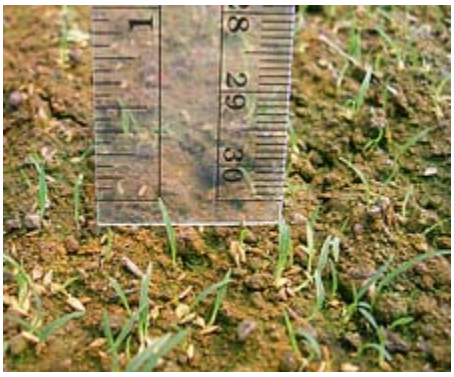

Fig. 5. 'Zenith' zoysiagrass seedlings 14 days after seeding. Most seeds have germinated, but this stand is not quite mature enough to consider emergence (a uniform stand of one-leaf seedlings about 0.5 inches tall). If emergence is judged too soon, herbicide injury will be more severe. Scale is with inches on the left.

Table 2. Herbicide safety margins when applied at various timings for use on zoysiagrass seedlings and the target weeds controlled. Listed in approximate order of least phytotoxic to most phytotoxic on zoysiagrass seedlings.

Herbicide(s)	**Rate** (lb a.i. /acre)	**Target weeds controlled preemergently or postemergently**	**Pre or Post**[u]	**Margin of safety (delay before or after emergence**[v]**)**
Siduron (Tupersan)	6.0	Crabgrass, goosegrass, annual bluegrass	Pre	Apply any time before or after seeding (7,22,29,31).
Quinclorac[w] (Drive)	0.75	Crabgrass, clover and other broadleaves	Post	Little to no phytotoxicity. Apply any time before or after seeding (7,29,33,34).
Pronamide (Kerb)	1.0	Crabgrass, goosegrass, annual bluegrass, perennial ryegrass	Pre + Post	No phytotoxicity. Apply any time after emergence (30).
MSMA	2.06	Crabgrass, goosegrass, dallisgrass	Post	Apply any time after emergence, there will be some phytotoxicity (30).
Trifloxysulfuron (Monument)	0.026	Annual bluegrass, perennial ryegrass, nutsedge	Post	Phytotoxicity mild[x]. Safe[y] to apply 1 WAE[z] or later (33).
Carfentrazone[w] (Quicksilver)	0.031	Clover, spurge, other broadleaves	Post	Phytotoxicity mild. Safe to apply 1 WAE or later (33). Label states "delayed until at least 14 days after emergence to avoid extended discoloration."
Oxadiazon (Ronstar)	3.0	Crabgrass, goosegrass, annual bluegrass	Pre	Phytotoxicity mild. Safe to apply 1 WAE or later (7,30).
Trifloxysulfuron +Carfentrazone	0.026 +0.031	Annual bluegrass, perennial ryegrass, nutsedge, clover, spurge, other broadleaves	Post	Phytotoxicity mild. Safe to apply 1 WAE or later (33).
Quinclorac +Carfentrazone	0.75 +0.031	Clover, spurge, and other broadleaves	Post	Phytotoxicity mild. Safe to apply 1 WAE or later (33).
Clopyralid (Lontrel) +MSMA	0.80 +2.0	Crabgrass, goosegrass, dallisgrass, clover, spurge, other broadleaves	Post	Phytotoxicity mild. Safe to apply 2 WAE or later (34).
Quinclorac +MSMA	0.375 +2.0	Crabgrass, goosegrass, dallisgrass, clover, spurge, other broadleaves	Post	Phytotoxicity mild. Safe to apply 2 WAE or later (34).
2,4-D +dicamba +mecoprop (Trimec Classic) +MSMA	0.844 +0.09 +0.22 +2.0	Crabgrass, goosegrass, dallisgrass, clover, spurge, other broadleaves	Post	Phytotoxicity mild. Safe to apply 2 WAE or later (31,34).
Trifloxysulfuron +MSMA	0.026 +2.0	Annual bluegrass, perennial ryegrass, nutsedge, crabgrass, goosegrass, dallisgrass	Post	Phytotoxicity mild. Safe to apply 2 WAE or later (34).
Dithiopyr (Dimension)	0.50	Crabgrass, goosegrass, annual bluegrass	Pre + Post	Safe to apply 2 WAE or later (28,29).
Dithiopyr +MSMA	0.5 +2.06	Crabgrass, goosegrass, dallisgrass, annual bluegrass	Pre + Post	Safe to apply 2 WAE or later (28). No herbicide injury visible two weeks after application.
Clopyralid +triclopyr (Confront) +MSMA	0.093 +0.278 +2.0	Crabgrass, goosegrass, dallisgrass, clover, spurge, other broadleaves	Post	Phytotoxicity medium. Safe to apply 2 WAE or later (34).

(continued)

Table 2. (continued).

Herbicide(s)	Rate (lb a.i. /acre)	Target weeds controlled preemergently or postemergently	Pre or Post[u]	Margin of safety (delay before or after emergence[v])
Foramsulfuron (Revolver) +MSMA	0.026 +2.0	Annual bluegrass, perennial ryegrass, crabgrass, goosegrass, dallisgrass	Post	Phytotoxicity medium. Safe to apply 2 WAE or later (34).
Flazasulfuron (Katana) +MSMA	0.019 +2.0	Perennial ryegrass, broadleaf weeds, sedges, crabgrass, goosegrass, dallisgrass	Post	Phytotoxicity medium. Safe to apply 2 WAE or later (34).
Foramsulfuron	0.027	Annual bluegrass, perennial ryegrass, dallisgrass	Post	Phytotoxicity medium. Apply 3 WAE or later (30)
Fluazifop (Fusilade)	0.062	Crabgrass, goosegrass, bermudagrass	Post	Phytotoxicity medium. Apply 3 WAE or later (30).
Metsulfuron (Manor) + MSMA	0.021 +2.0	Crabgrass, goosegrass, dallisgrass, perennial ryegrass, broadleaves	Post	Severe herbicide injury and reduction in zoysiagrass coverage when applied 2 WAE.
Fenoxaprop +Clopyralid +triclopyr	0.122 +0.093 +0.278	Crabgrass, goosegrass, clover, spurge, other broadleaves	Post	Severe herbicide injury and reduction in zoysiagrass coverage when applied 2 WAE.
Fenoxaprop (Acclaim)	0.122	Crabgrass, goosegrass	Post	Severe phytotoxicity and reduction in zoysiagrass coverage (30).

[u] Herbicides controlled target weeds preemergently (Pre) or postemergently (Post) or both (Pre+Post).

[v] Emergence is defined as a uniform stand of one-leaf seedlings about 0.5 inches tall.

[w] Labeled for use on zoysiagrass seedlings

[x] Herbicides causing acceptable phytotoxicity were classified as mild, those causing phytotoxicity below acceptable limits without killing zoysiagrass seedlings were classified as medium, and those killing zoysiagrass seedlings were classified as severe.

[y] Herbicides were deemed to be safe when an application did not cause any reduction in seedling coverage.

[z] Weeks after zoysiagrass seedling emergence.

Carfentrazone, MSMA (monosodium salt of methylarsonic acid), oxadiazon (3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2-(3H)-one), pronamide, quinclorac, siduron (N-(2-methylcyclohexyl)-N'-phenylurea), and trifloxysulfuron (1-(4,6-dimethoxypyrimidin-2-yl)-3-[3-(2,2,2-trifluoroethoxy)-2-pyridylsulfonyl]urea) are among the herbicides that are safest to use on zoysiagrass seedlings. Siduron is safe to use on Zenith and Korean common zoysiagrass seedlings for preemergence control of annual grassy weeds and should be applied at the time of seeding (7,22,29,31). After zoysiagrass has germinated, oxadiazon is also useful for preemergence weed control (26) and can be applied 1 week after Zenith zoysiagrass seedling emergence (WAE) (30) which is at least 26 days later than it is safe to apply siduron.

Quinclorac and MSMA are safe to use for postemergence control of annual grassy weeds on Zenith zoysiagrass seedlings as early as seedling emergence (7,29,30,33,34). More phytotoxicity can be expected with MSMA than quinclorac, but effects are short lived and herbicide damage from early applications can be justified by decreased weed competition (Figs. 6 and 7). Quinclorac and carfentrazone offer selective postemergence control of broadleaf weeds. Quinclorac can be applied at emergence or later, whereas carfentrazone can be applied 1 WAE or later to Zenith zoysiagrass seedlings (33).

Fig. 6. Damage to 'Zenith' zoysiagrass seedlings caused by one application of quinclorac (Drive) at 2 weeks after emergence. Picture was taken 10 days after herbicide application.

Fig. 7. Damage to 'Zenith' zoysiagrass seedlings caused by one application of 2,4-D + dicamba + mecoprop (Trimec Classic) + MSMA at 2 weeks after emergence. Picture was taken 10 days after herbicide application.

Pronamide provides selective postemergence control of annual bluegrass and perennial ryegrass without causing damage or growth reduction to Zenith zoysiagrass seedlings (30). This product is registered as a restricted use pesticide which could preclude its use on some golf courses. Trifloxysulfuron also controls annual bluegrass and perennial ryegrass, but is not safe until 1 WAE or later and causes mild phytotoxicity to Zenith zoysiagrass seedlings (33,34). Glyphosate can also be applied in colder climates in late winter to eradicate cool-season turfgrasses such as perennial ryegrass and annual bluegrass from dormant zoysiagrass (36).

Herbicides such as metsulfuron (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid) and fenoxaprop ((±)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid) cause significant reduction in Zenith zoysiagrass coverage when applied to seedlings and should not be used during establishment (Figs. 8 and 9) (30,34). Other herbicides such as fluazifop ((R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid) and foramsulfuron can damage Zenith zoysiagrass seedlings (30,34) and thus should be used on seedlings only when absolutely necessary and no other weed control options are available (Fig. 10).

Fig. 8. Damage to 'Zenith' zoysiagrass seedlings caused by applications of fenoxaprop (Acclaim) 0 and 7 days after emergence.

Fig. 9. Damage to 'Zenith' zoysiagrass seedlings caused by one application of fenoxaprop + clopyralid + triclopyr (Acclaim + Confront) at 2 weeks after emergence. Picture was taken 10 days after herbicide application.

Fig. 10. Damage to 'Zenith' zoysiagrass seedlings caused by one application of foramsulfuron (Revolver) + MSMA at 2 weeks after emergence. Picture was taken 10 days after herbicide application.

Some damage or phytotoxicity may result from herbicides applied shortly after emergence of zoysiagrass. However, under heavy weed pressure the risk of herbicide damage from early applications may be justified by decreased weed competition eventually allowing increased zoysiagrass coverage.

Post-Seeding Fertilization

Nitrogen (N) fertilization is often increased to hasten establishment of seedlings. Research on establishing seeded zoysiagrass found that increasing monthly nitrogen fertilization from 1.0 to 2.0 lb/1000 ft^2 does not improve establishment (29). This is similar to work with Meyer in which increasing the annual nitrogen from 1.0 to 4.0 lb/1000 ft^2 did not hasten establishment from plugs in the initial year (11). Although some nitrogen should be applied during seeded zoysiagrass establishment, applications should be kept to a minimum and not exceed 1.0 lb/1000 ft^2/month (29). Zoysiagrass should receive 3.0 to 4.0 lb/1000 ft^2/year when used on golf course tees, 1.5 to 3.0 lb/1000 ft^2/year when used in golf course fairways, and 1.0 to 2.0 lb/1000 ft^2/year when used on golf course roughs after the initial year of establishment (26).

Post-Seeding Traffic

Golf carts allow disabled golfers to enjoy the game and help increase golf course revenue, but carts cause turf wear and soil compaction (4). Turfgrass seedlings including zoysiagrass are adversely affected by soil compaction and wear (5,42). Trafficking zoysiagrass after seeding reduces zoysiagrass emergence and coverage by more than 50% (42). Therefore, limiting or diverting cart and equipment traffic after seeding is strongly advised. After fully established, seeded zoysiagrass cultivars exhibit better wear tolerance than most vegetatively established *Z. japonica* cultivars (25).

Shade

Zoysiagrass is considered to have good shade tolerance compared to other warm-season grasses (3). However, only recently have the effects of shade on seedling emergence and growth in the field been evaluated. Zuk et al. (43) tested three levels of shade and found that zoysiagrass seedling emergence and growth decreased as shade levels increased. Specifically, germination and growth were significantly reduced when subjected to 60% of normal solar irradiance. This was due, in part, to the reduced soil temperatures in shaded plots, and to a greater extent, because lower surface irradiance inhibited seed germination and seedling growth (43). Therefore, trees should be removed or heavily pruned prior to establishment in areas that are shaded.

Winter Hardiness

Seeded zoysiagrass survives winters in the transition zone with little damage (25). Preliminary research in Indiana has also found that seeded zoysiagrass cultivars have excellent freeze tolerance, but seedlings could be subject to desiccation in western regions of the transition zone. Winter survival of seeded zoysiagrass does not appear to be influenced by seeding date, seeding rate, or nitrogen fertility (29).

Costs

As mentioned previously, practices such as strip-sodding and sprigging can be used instead of solid-sodding to reduce establishment costs, but these techniques may require two or more years before zoysiagrass is established. Additionally, zoysiagrass can be established by seed more rapidly and at a lower cost than strip-sodding or sprigging (Table 3). Seed typically costs about $20/lb of PLS. If seeded at a rate of 1.0 lb PLS per 1000 ft^2, then seed costs per acre are about $900. The cost of seed drops to about $120/acre if zoysiagrass is strip-seeded.

Table 3. Summary of establishment methods and costs for zoysiagrass.

	Establishment Method					
	Vegetative			Seed		
	Sprigging	Strip-sodding	Solid-sodding	Seeding[w]	Strip-seeding[x]	Scalp-seeding[y]
Establishment cost/acre[z]	$3,000	$5,000	$16,000	$900	$120	$900
Time until 90% coverage	2-3 yrs	2-3 yrs	0 days	1 yr	4-5 yrs	4-5 yrs

[w] Seeding into fallow ground or after a broadcast application of glyphosate.

[x] Strip seeding is based upon 2-inch wide rows on 15-inch centers.

[y] Seeding into a cool-season turf that has been scalped at a low mowing height before seeding and for several weeks after seeding.

[z] Cost variable by cultivar. Cultivars used for price estimates in this table are Meyer zoysiagrass (vegetative) and Zenith zoysiagrass (seeded). Labor is not included in establishment cost for seeded varieties. Herbicide costs are not factored into the establishment costs because of the variability between sites and methods. Seeding costs are based on 1.0 lb pure live seed per 1000 ft^2 at a cost of $20.65/pound of PLS.

Herbicide costs during establishment vary based upon weed pressure and site preparation and seeding technique. A typical herbicide program during establishment might include an application of glyphosate (except scalping method) prior to seeding, siduron immediately after seeding, quinclorac or MSMA as needed to control summer annual grassy weeds, carfentrazone to control summer annual and perennial broadleaves, and pronamide to selectively control perennial grassy weeds two years after seeding (except when seeding into a tilled seedbed or broadcast-applying glyphosate before seeding) with an estimated cost ranging from $150 to $450/acre. The estimated establishment costs are as follows if herbicide costs are added to seed costs. Estimated establishment cost excluding labor is about $1,200/acre including four herbicide applications when seeding into a tilled seedbed. When broadcast-applying glyphosate prior to seeding, estimated establishment cost excluding labor is $1,200/acre including four herbicide applications and $420/acre including five herbicide applications when strip-applying glyphosate and strip-seeding. If the scalping method is used, then estimated establishment cost excluding labor is $1,200/acre including four herbicide applications.

Summary

The high costs of vegetative establishment have prevented many golf course superintendents from establishing zoysiagrass in spite of reduced long-term maintenance inputs and costs. Seeded zoysiagrass cultivars afford all of the benefits of vegetative cultivars and have quality similar to Meyer. This paper summarizes research that demonstrates how seeded zoysiagrass fairways can be established successfully. Establishing seeded zoysiagrass will reduce irrigation, pesticide and fertilizer inputs and costs when compared to inputs needed to maintain a cool-season sward. Zoysiagrass use can result in transition zone golf courses that are more environmentally friendly and sustainable, and seeded zoysiagrass makes this goal more attainable.

Summary of Procedures for Establishing Seeded Zoysiagrass

Procedures for establishing seeded zoysiagrass in tilled soil:

1. Apply glyphosate to designated areas.
2. Lightly till area and correct any drainage problems.
3. Seed 1.0 to 2.0 lb PLS per 1000 ft^2 of zoysiagrass when soil temperatures reach 68°F (early June).
4. Apply a starter fertilizer at 1.0 to 1.5 lb P_2O_5 per 1000 ft^2 or as soil tests recommend.
5. Apply siduron immediately after seeding if high annual weed pressure is anticipated.
6. Cover with germination blanket for 14 days after seeding if budget allows.
7. Maintain a moist seedbed with light, frequent irrigation until plants mature to a point where frequency can be reduced and amount increased.
8. Apply herbicides for weed control as soon as possible depending upon safety of individual herbicide, weed species and weed pressure (multiple herbicide applications are usually necessary).
9. Begin mowing at 0.5 to 0.75 inch as needed.
10. Apply 1.0 lb N per 1000 ft^2 in June, July and August the initial year.
11. Expect 90% zoysiagrass coverage in 75 or more days assuming adequate soil temperatures and moisture. Estimated establishment cost excluding labor is $1,200/acre including four herbicide applications.

Procedures to convert existing fairways to seeded zoysiagrass using a broadcast application of glyphosate:

1. Apply glyphosate to designated areas.
2. Correct any drainage problems.
3. Core aerify and verticut aggressively to break up soil cores and prepare the seedbed.
4. Seed 1.0 to 2.0 lb PLS per 1000 ft^2 of zoysiagrass when soil temperatures reach 68°F (early June).
5. Apply a starter fertilizer at 1.0 to 1.5 lb P_2O_5 per 1000 ft^2 or as soil tests recommend.
6. Apply siduron immediately after seeding if high annual weed pressure is anticipated.
7. Maintain a moist seedbed with light, frequent irrigation until plants mature to a point where frequency can be reduced and amount increased.
8. Apply herbicides for weed control as soon as possible depending upon safety of individual herbicide, weed species and weed pressure (multiple herbicide applications are usually necessary).

9. Begin mowing at 0.5 to 0.75 inch as needed.
10. Apply 1.0 lb N per 1000 ft^2 in June, July and August the initial year.
11. Expect 90% zoysiagrass coverage in 90 or more days assuming adequate soil temperatures and moisture. Estimated establishment cost excluding labor is $1,200/acre including four herbicide applications.

Procedures to convert existing cool-season fairways to zoysiagrass using strip seeding:

1. Identify a contractor who is licensed to use the strip-seeding procedure. To locate a contractor, contact National Institute for Strategic Technology Acquisition and Commercialization. 1500 Hayes Dr., Manhattan, KS 66502. Phone: (785) 532-3900; email: nistac@ksu.edu. For best results areas should be strip-seeded in early June.
2. Tank mix siduron with glyphosate during strip-seeding if high annual weed pressure is anticipated.
3. Apply a starter fertilizer at 1.0 to 1.5 lb P_2O_5 per 1000 ft^2 or as soil tests recommend.
4. Maintain a moist seedbed with light, frequent irrigation until plants mature to a point where frequency can be reduced and amount increased.
5. Apply herbicides for weed control as soon as possible depending upon safety of individual herbicide, weed species and weed pressure (multiple herbicide applications are usually necessary).
6. Begin mowing at 0.5 to 0.75 inch when zoysiagrass begins to tiller.
7. Apply 1.0 lb N per 1000 ft^2 in June, July and August the initial year.
8. Apply pronamide, foramsulfuron or trifloxysulfuron two to four years after seeding to remove existing cool-season turf and allow zoysiagrass to fill in voids. In colder climates, glyphosate can be applied to remove cool-season grasses from dormant zoysiagrass in late winter.
9. Expect 90% zoysiagrass coverage in 3 to 4 years. Estimated establishment cost excluding labor is $420/acre including five herbicide applications.

Procedures to convert existing cool-season fairways to zoysiagrass by scalping:

1. Scalp existing cool-season turf in areas to be seeded to a height of 0.25 inch or less and maintain at this height until zoysiagrass tillering begins.
2. Correct any drainage problems.
3. Core aerify and verticut aggressively to break up soil cores and prepare the seedbed.
4. Seed 1.0 to 2.0 lb PLS per 1000 ft^2 of zoysiagrass when soil temperatures reach 68°F (early June).
5. Apply a starter fertilizer at 1.0 to 1.5 lb P_2O_5 per 1000 ft^2 or as soil tests recommend.
6. Apply siduron immediately after seeding if high annual weed pressure is anticipated.
7. Maintain a moist seedbed with light, frequent irrigation until plants mature to a point where frequency can be reduced and amount increased.
8. Apply herbicides for weed control as soon as possible depending upon safety of individual herbicide, weed species and weed pressure (multiple herbicide applications are usually necessary).
9. Begin mowing at 0.5 to 0.75 inch when zoysiagrass begins to tiller.

10. Apply 1.0 lb N per 1000 ft^2 in June, July and August the initial year.
11. Apply pronamide, foramsulfuron or trifloxysulfuron two to four years after seeding to remove existing cool-season turf and allow zoysiagrass to fill in void areas. In colder climates, glyphosate can be applied to remove cool-season grasses from dormant zoysiagrass in late winter.
12. Expect 90% zoysiagrass coverage in 3 to 4 years. Estimated establishment cost excluding labor is $1,200/acre including four herbicide applications.

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