REVIEW & INTERPRETATION

Cultural Management of Weeds in Turfgrass: A Review

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ABSTRACT

Cultural management of weeds in turfgrass is the use of mowing, fertilization, irrigation, cultivation, planting, and turfgrass selection to affect weed populations. There is consensus in the literature on a few cultural factors influencing some weeds in cool-season turfgrasses. Taller mowing height, 4 to 8 cm, depending on turfgrass, reduces populations of crabgrasses (*Digitaria* spp.) in Kentucky bluegrass (*Poa pratensis* L.) and fescues (*Festuca* spp.). A high rate of N fertilization (100–300 kg N ha^{-1} yr^{-1}) reduces populations of crabgrasses, dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers), and other broadleaf weeds in cool-season turfgrasses. Annual bluegrass (*Poa annua* L.) may be favored by this high rate of fertilization. Fertilization of turfgrasses when they are not actively growing increases weeds. Slow-growing grasses such as zoysiagrasses (*Zoysia* spp.) have more weeds at high N fertilization rate. Environmental stresses including drought injury, unnecessary aeration or vertical mowing, biotic stress such as nematode and insect herbivory, and diseases contribute to weed colonization. Adapted cultivars and species of turfgrasses that are genetically resistant to biotic and environmental stresses have the fewest weed problems. Adapted turfgrasses can sometimes be effectively managed in the absence of herbicides, especially if they are well established. The generalized mechanisms for cultural management of weeds are poorly understood. Research is needed on optimizing the choices of herbicide and/or cultural practices as part of an integrated management system for turfgrass.

Cultural management of weeds in turfgrass is the use of mowing, fertilization, irrigation, cultivation, planting, and turfgrass selection to affect weed populations. Cultural management is important because it may reduce dependence on synthetic pesticides.

Chemical management of weeds in turfgrass originated about 1895 (Hansen, 1921). Following the discovery of the selective toxicity of synthetic organic herbicides such as 2,4-D (2,4-dichlorophenoxyacetic acid; Marth and Mitchell, 1944), there has been considerable research on chemical management of weeds in turfgrass, represented by >750 scientific papers published in refereed journals through 2002. During the same period, only 25 scientific papers were published emphasizing cultural management of weeds as they occur in turfgrass, according to the objectives stated in the papers or their titles. In another 28 scientific papers, cultural management effects on weeds in turfgrass were reported briefly. Other papers have contributed indirectly by studying growth and interactions among pasture plants, and by studying the biology of turfgrasses and weeds.

Bioherbicides are outside the definition of cultural management, although some such as corn gluten hydrosylate (McDade and Christians, 2001) are an alternative to synthetic chemical herbicides used in turfgrass. Inundation of weeds with selected microorganisms is another alternative to synthetic chemicals, with examples *Xanthomonas campestris* pv. *poannua* for biocontrol of annual bluegrass (Johnson, 1994; Johnson et al., 1996; Zhou and Neal, 1995); *Bipolaris setariae* (Sawada) Shoemaker and *Pyricularia grisea* (Cooke) Sacc. for biocontrol of goosegrass [*Eleusine indica* (L.) Gaertn.] (Figliola et al., 1988); and *Phoma herbarum* Westend. for biocontrol of dandelion (Neumann and Boland, 1999). These *inundative* biocontrol agents are applied at high concentrations for immediate effect, do not sustain long-term damage to weeds, and are sensitive to environmental conditions. Classical or *inoculative* biological control of turfgrass weeds, if it were successful, would be closely allied with cultural management, because cultural practices could be adjusted to assist the establishment of weed natural enemies.

Integrated pest management (IPM) is the combined and thoughtful use of multiple approaches such as chemicals and cultural practices for pest management. The lack of research on effective, low-cost IPM methods is an impediment to reducing chemical usage in lawn care and landscape management (Latimer et al., 1996). Extension recommendations often indicate that a dense, healthy turfgrass stand is the best defense against weed colonization, and can be accomplished by proper mowing, watering, and fertilization. While this seems reasonable, the methods are often stated in generalities, and are not based on published research. The objectives of the present review and interpretation are to synthesize all the diverse and scattered scientific information on cultural management of weeds in turfgrass, and to describe opportunities for future research.

Turfgrass Selection and Establishment

Weeds can be managed by choosing a turfgrass species and cultivar that is resistant to damage by environmental stresses, including biotic stresses. For a particular situation, a well-adapted cultivar establishes and covers the ground quickly, and may persist for many years, thus providing few gaps in the canopy for weeds to colonize. Improper herbicide use can injure turfgrasses

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Abbreviations: Ep, Class A pan evaporation; ET, evapotranspiration; IPM, integrated pest management; LAI, leaf area index.

and reduce the rate of establishment, resulting in more weed problems (Smith and Callahan, 1968). Kentucky bluegrass cultivars exhibited year-to-year variation in density, which determined weediness (Nelson, 1985). Performance in the early years can be misleading; at least 5 yr of cultivar testing is required before relative stability is achieved. On the basis of an 8-yr shade trial of cool-season turfgrass cultivars, establishment success may not be a good predictor of long-term performance (Gardner and Taylor, 2002).

Adaptation to Biotic Stresses

The sting nematode (*Belonolaimus longicaudatus* Rau) reduces the density of 'Tifgreen' hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy], and is associated with high abundance of prostrate spurge {*Euphorbia maculata* L. [= *Chamaesyce maculata* (L.) Small]} (Brodie and Burton, 1967). As a demonstration, the nematicide fenamiphos [ethyl 3-methyl-4-(methylthio)phenyl-(1-methylethyl)phosphoramidate] reduced sting nematode density by 86% or more during a year after its application to hybrid bermudagrass turf, thus reducing prostrate spurge from 20% cover to 0.3% cover, because of better growth of the bermudagrass (Lucas, 1982). In sand soils in Florida, the sting nematode severely stresses and damages several species of turfgrass, and probably explains the difficulty of maintaining stands of zoysiagrasses and bermudagrasses (*Cynodon* spp.). Better-adapted genotypes of zoysiagrass, with lower densities of sting nematode infestation, have less abundant weed populations (Busey et al., 1982). There are significant differences in weed cover among zoysiagrasses in California (Henry et al., 1989), because of differences in the competitiveness of zoysiagrass cultivars. The cultivar with the least weed cover was released as 'El Toro' Japanese zoysiagrass (*Z. japonica* Steud.).

Under conditions of severely damaging mole crickets (*Scapteriscus* spp.) and resulting competition from a mixed population of weeds, especially thin paspalum (*Paspalum setaceum* Michx.) and purple nutsedge (*Cyperus rotundus* L.), bermudagrass genotypes show differential survival and coverage (Busey, 1986). Cultivars of St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] that are susceptible to the southern chinch bug, *Blissus insularis* Barber, are colonized by weeds following chinch bug outbreak and damage (Busey, 1977, unpublished data). In Ohio, 'Park' Kentucky bluegrass is infested by weeds as a consequence of severe attacks by the fungus *Drechslera poae* (Baudys) Shoemaker (Davis, 1958). A factor that could be involved in colonization of creeping bentgrass {*Agrostis palustris* Huds. [= *A. stolonifera* L. var. *palustris* (Huds.) Farw.]} by annual bluegrass is that the turf is weakened in pitted scars from injury by dollarspot disease caused by *Sclerotinia homoeocarpa* F.T. Bennett (Waddington et al., 1978).

Adaptation to Physiological Stresses

Cold damage, which is worst on 'Floratam' St. Augustinegrass when it is heavily fertilized, leads to weed infestation the following year (Laiche, 1979). Under reduced irrigation in California, perennial ryegrass (*Lolium perenne* L.) is more susceptible than other turfgrasses to colonization by spotted (= prostrate) spurge (Gibeault et al., 1985). This is attributed to the poor performance of perennial ryegrass during the summer months.

After 3 yr with no irrigation and no fertilization, 'Bighorn' blue fescue {*Festuca ovina* L. subsp. glauca (Lam.) W.D.J. Koch [= *F. ovina* var. *glauca* (Vill.) W.D.J. Koch]} and 'Aurora' hard fescue {*F. longifolia* auct. non Thuill. [= *F. trachyphylla* (Hack.) Krajina]} are more resistant to colonization by smooth crabgrass [*Digitaria ischaemum* (Schreb. ex Schweigg.) Schreb. ex Muhl.] and white clover (*Trifolium repens* L.) than either 'Silverado' or 'Rebel II' tall fescue (*F. arundinacea* Schreb.) (Dernoeden et al., 1994). Despite providing very good quality during the first year after seeding, the poor performance of the tall fescue cultivars is explained by their defoliation caused by spring drought. On the basis of herbicide split-plot treatments, tall fescue cultivars could not be maintained under the low maintenance regime without the use of herbicides, but blue fescue and hard fescue had insignificant weed cover, regardless of herbicide treatment.

'Silverado' tall fescue has more smooth crabgrass infestation than 'Rebel II,' but the two tall fescues do not differ in white clover infestation (Dernoeden et al., 1994). Among bermudagrass cultivars grown in Georgia, infestation of common chickweed [*Stellaria media* (L.) Cyrillo] was less in 'Tifway' and 'Ormond' than in Tifgreen and 'Tifdwarf' (Johnson, 1983). This was probably because of differential injury to bermudagrass from high rate phenoxy herbicide treatments, though genetic differences in height (Tifgreen and Tifdwarf are shorter) were not considered. Weediness in turfgrass cultivars may thus arise from several different mechanisms.

Planting and Establishment

Rapid establishment of a turfgrass is important for resisting weed colonization, and higher planting densities sometimes reduce weed cover. With Kentucky bluegrass, planting at 90 kg seed ha^{-1} instead of 45 kg seed ha^{-1} reduced weed cover from 68 to 47%, based on the average of two dates in the second month after planting (Beard et al., 1980). With Kentucky bluegrass, five growing seasons are required for stand densities to converge (Brede and Duich, 1982), therefore planting rate may have a long-term effect on weeds. A higher seeding rate of bahiagrass (*Paspalum notatum* Flügge) slightly compensates for weedy conditions; for example, 'Argentine' bahiagrass can be planted at 170 kg seed ha^{-1} for acceptable establishment by the second growing season in weedy conditions, but under weed-free conditions, acceptable establishment in the first growing season requires planting 130 kg seed ha^{-1} (Busey, 1989). No bermudagrass colonization occurred in tall fescue seeded at the highest rates, 293 and 780 kg seed ha^{-1}, and mown at the higher height, 5.7 cm, vs. 1.9 cm (Brede, 1992). Tall fescue is more effective than perennial ryegrass in suppressing colonization of kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.) (Elmore et al., 1997). Denser tall fescue cultivars such as 'Bonsai' and 'Olympic' are more competitive than the older cultivar 'Fawn'.

Timing of cultural practices affects weediness. Fertilizing bahiagrass at the time of seed planting results in more weeds than fertilization at the three-leaf seedling stage, 5 wk after planting (Busey, 1992). Acceptable buffalograss [*Buchloë dactyloides* (Nutt.) Engelm.] establishment was achieved in Nebraska by seed planting from late April through June (Frank et al., 1998). The negative relationship between buffalograss establishment and weed cover indicated that weed interference was the primary factor limiting establishment.

Certain mulches such as Turfiber, a natural wood cellulose fiber, can increase soil moisture, reduce extreme high soil temperature, and increase turfgrass seedling establishment (Barkley et al., 1965). While several mulches reduced soil evaporation and eliminated weed growth, alfalfa hay and certain turfgrass clippings were more effective at weed suppression than oat straw (Shearman et al., 1979). Bermudagrass sprig establishment was increased with straw mulch, and broadleaf and annual grass weeds were reduced by 78%, in comparison with unmulched plantings (Sowers and Welterlen, 1988). The advantages of mulch may be negated if it contains weeds. Another approach to managing weed populations during establishment is mat-seeding, the planting of seed either on or under a bioorganic fiber mesh ≈7.5 mm thick (Hensler et al., 2001). While coverage of six species of warm-season turfgrasses is less with mat-seeding than directly in the ground, an advantage is the reduction in weed populations.

The success of turfgrass establishment by use of companion grasses varies depending on the circumstances. Annual ryegrass (*Lolium multiflorum* Lam.) is sometimes useful as a winter cover crop before seeding the kleingrass (*Panicum coloratum* L.) in pastures (Bovey et al., 1990). But when annual ryegrass is too dense, it prevents the growth of kleingrass, so a suitable strategy is to remove the ryegrass through grazing or a nonselective herbicide such as glyphosate [*N*-(phosphonomethyl)glycine] before kleingrass planting. When perennial ryegrass is seeded with Kentucky bluegrass, mowing early and close (the second week after sowing and at 1.3-cm height) optimally favors the Kentucky bluegrass (Brede and Duich, 1984b). Similar results were observed for tall fescue that was seeded with annual ryegrass for soil stabilization, that is, a single early, close mowing (0–3 d after annual ryegrass emergence, at a 0–7 mm height) favored tall fescue establishment (Brede and Brede, 1988). Other companion grasses such as browntop millet {*Panicum ramosum* L. [= *Urochloa ramosa* (L.) T. Q. Nguyen]} and red millet (*Panicum* spp.) are very deleterious to warm-season grass establishment (Dudeck and Peacock, 1986) and bahiagrass (Busey, 1989).

Preplant cultural methods to reduce weed seed populations have mixed results. In the absence of a cover crop, solarization reduces annual bluegrass seed survival by 89% or more in the upper 5 cm of soil, but may enhance seed survival below 5 cm (Peachey et al., 2001). In the same study, cover crops generally increase survival of annual bluegrass seeds buried between 2.5 and 15 cm deep. While mechanical preplant control of weeds is often a key to managing field crops, turfgrass presents relatively few opportunities for this practice; for example, sod production and new turf establishment.

Competitiveness and Stand

Differential turfgrass resistance to weeds may be expected on the basis of differences among turfgrass species and cultivars in morphology and canopy characteristics. This is not substantiated. Although an improved cultivar of tall fescue, 'Mustang', has greater shoot density compared with 'Kentucky-31' tall fescue, there is no difference in their susceptibility to invasion by bermudagrass (Brede, 1992). Mown at a 2- and 3-cm height, 11 Kentucky bluegrass cultivars respond with an increase in leaf angle (the angle between the third youngest leaf and the bud leaf), but leaf angle is not related to the ability to compete with annual bluegrass (Eggens, 1982). In mixtures of cool-season grasses evaluated under low maintenance in Alberta, weed encroachment is generally lower in mixtures than in individual species; but some individual species, including low growers among the fine fescues (*Festuca* spp.), resist weed encroachment (McKernan et al., 2001). Seeding rate of species in the mixtures was adjusted so that the same total seed count was planted as with monoculture plantings. Mixtures of Kentucky bluegrass and perennial ryegrass achieve 8% higher leaf area index (LAI) compared with monocultures (Brede and Duich, 1984a), which may help explain the weed-control advantage of mixtures.

Much of what is known about the competitive ability of turfgrasses is learned from a comparison of their relative competitiveness with one another in varying environments. When short-leaved and long-leaved perennial ryegrass genotypes compete under infrequent cutting, the competition for light favors the long-leaved genotype (Hazard and Ghesquiere, 1995).

In the greenhouse, 'Merion' Kentucky bluegrass predominates over creeping red fescue (*Festuca rubra* L.) at a high level of N fertilization, but creeping red fescue predominates at a low level of N fertilization (Juska et al., 1955). This demonstrates that the effects of cultural management on species dominance are a subset of the interactive relationship of genotypes and the environment.

Creeping bentgrass is competitive with other turfgrasses when mown close (Davis, 1958). It is possible to separate belowground vs. aboveground interactions of annual bluegrass, Kentucky bluegrass, and perennial ryegrass by growing them in pairwise combinations in boxes, with partitions either belowground or aboveground (Brede and Duich, 1986). On the basis of root and shoot growth parameters, competitive ability of perennial ryegrass is generally belowground and causes a lesser green color in annual bluegrass.

Tall fescue has been occasionally reported to have allelopathic effects on other species, such as birdsfoot trefoil (*Lotus corniculatus* L.), red clover (*Trifolium pratense* L.), and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] (Peters and Mohammed Zam, 1981; Luu et al., 1982). Leachate from annual ryegrass has a severe inhibitory effect on four forage legume species, and also reduces root length (Cope, 1982). Allelopathic effects of leachates from tall fescue and four other cool-season turfgrasses occur in Petri-dish bioassays, but not in soil; therefore, the production of significant amounts of allelochemicals in a field environment is doubtful (Lickfeldt et al., 2001). Water extracts of buffalograss cultivars differ in concentration of six different phenolic acids, and root growth of annual bluegrass seedlings was severely inhibited by the extracts (Wu and Guo, 1997). Weed species may also potentially have allelopathic effects on turfgrasses.

The suppression of woody plants by turfgrasses has been widely reported (e.g., Fales and Wakefield, 1981). One of the benefits of a maintained turfgrass cover is that succession to woody vegetation is often delayed. A uniform turf cover probably reduces mowing requirements, besides providing easements and roadsides with better visibility and safety. Direct competition for available N is the simplest explanation for interference in growth of dogwood (*Cornus florida* L.) surrounded by a mixed turfgrass planting of Kentucky bluegrass and red fescue. Only subsurface fertilization, but neither topdressed fertilizer nor subsurface irrigation, corrected the inhibitory effects of turfgrass growing near the base of dogwood and within 70 cm of the tree trunks. In the same study, allelopathic exudates were also responsible for root inhibition of forsythia (*Forsythia* × *intermedia* Zabel) (Fales and Wakefield, 1981).

Periodic Cultural Practices

Mowing

Mowing height is the clearest and most well documented cultural factor affecting weed populations in turfgrass. In cases where a significant effect has been detected, within the mowing heights studied, the lower mowing height is always associated with more weeds in turfgrass.

Low Mowing Height Increases Crabgrasses. Studies of crabgrass infestation in cool-season turfgrasses have always shown that lower mowing height increases weed density (Fig. 1) in Chewings fescue {*Festuca rubra* var. *commutata* Gaudin [= *F. rubra* subsp. *fallax* (Thuill.) Nyman]} (Jagschitz and Ebdon, 1985); Kentucky bluegrass (Niehaus, 1974; Dunn et al., 1981); tall fescue (Hall, 1980; Dernoeden et al., 1993; Voigt et al., 2001); and in a comparison of tall fescue and several fine fescue species (Dernoeden et al., 1998).

In bermudagrass, mowing height effects were observed in both crabgrass and dandelion densities, but the effects were slight and inconsistent in direction (Callahan and Overton, 1978). In the same study, bermudagrass overseeded with perennial ryegrass provided greater perennial ryegrass stand density at a lower mowing height, 42% at 2.5 cm, compared with 24% at a 5.1-cm mowing height (average of June and September evaluations). Artificial seeding with perennial ryegrass can thus serve as a weed surrogate to understand the role of canopy reduction in weed establishment.

Low Mowing Height Increases Other Weeds. Populations of weeds other than crabgrasses are also favored by low mowing, but the evidence is sporadic. Low mowing height (2.5 cm) increases green kyllinga (*Kyllinga brevifolia* Rottb.) infestation 2 to 5 times in bermudagrass

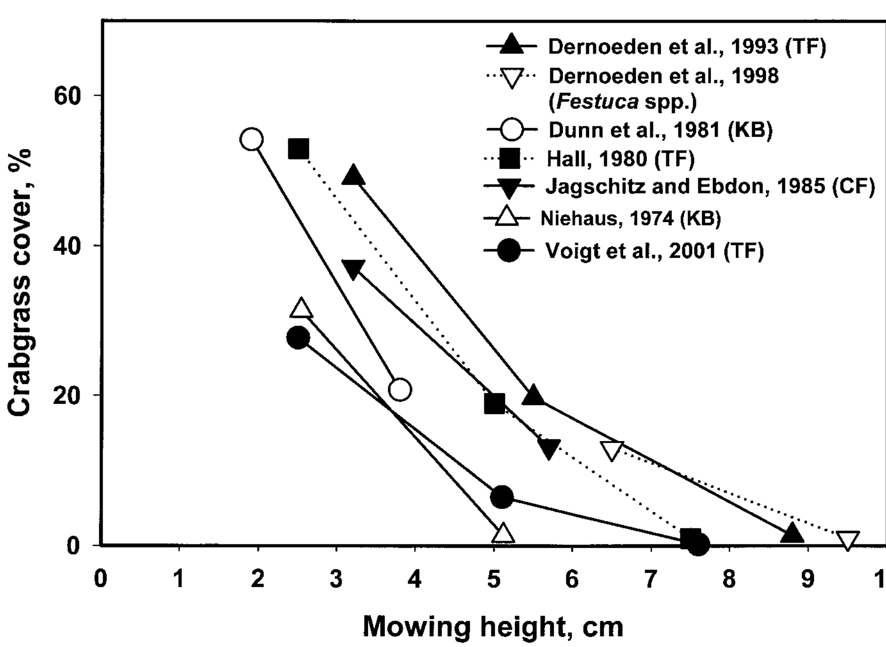

Fig. 1. Relationship of mowing height to cover of crabgrasses [smooth crabgrass (*Digitaria ischaemum*) or not specified (*Digitaria* spp.)] in cool-season turfgrasses. Species of turfgrass is Kentucky bluegrass (KB, *Poa pratensis*), Chewings fescue (CF, *Festuca rubra* subsp. *fallax*), or tall fescue (TF, *F. arundinacea*).

turf, compared with a 5.0-cm mowing height (Lowe et al., 2000). Species of *Kyllinga*, a relatively low growing, spreading weed, are highly competitive with bermudagrass (Kawabata et al., 1994). In an initially perennial ryegrass sports turf, annual bluegrass increases with reduced mowing height (Adams, 1980); averaged across fertility levels, annual bluegrass cover was 34% at a 1.25-, 20% at a 2.5-, and 9% at a 7.5-cm mowing height. In carpetgrass {*Axonopus affinis* Chase [=*A. fissifolius* (Raddi) Kuhlm.]}, annual bluegrass has higher cover at a 3.8-cm mowing height, 30.8%, compared with 8.6% at a 7.6-cm mowing height, based on averages across N fertilization rates (Bush et al., 2000).

During 5 yr, the persistence of Kentucky bluegrass and fine fescues is favored in competition with weeds (mixture of dandelion, white clover, and crabgrass), by mowing at 5.1 cm vs. 1.9 cm (Davis, 1958). In the same study, zoysiagrass, bermudagrass, and creeping bentgrass had few weeds. Broadleaf weeds, such as mock-strawberry [*Duchesnea indica* (Andrews) Focke] and common blue violet (*Viola sororia* Willd.) are also reduced at higher mowing height (6 cm vs. 4 cm) tall fescue (Gray and Call, 1993). In that study, N fertilization rate, discussed later, interacted with mowing height. High mowing and high N fertilization rate reduced common blue violet to the greatest degree, but mowing height was the more important factor.

Mowing to Prevent Weed Colonization. With their protected growing points, grasses survive and predominate in ecosystems with periodic defoliation by fire, grazing, or mowing. It is expected that mowing too high or too infrequently would increase weed colonization, just as mowing too low encourages crabgrasses and other weeds, and an optimum intermediate mowing height and frequency would maintain a grass monoculture. Possible weed control benefits of mowing are that timely mowing that is low enough would cut seedheads and prevent weed seeds from maturing; also, most dicotyledonous plants are eventually killed by mowing.

In an *Agrostis–Festuca* pasture, when plots were not mown until summer, the weed seed bank doubles (Williams, 1984). This effect, delayed mowing increasing weed density, has not been reported in turfgrasses, and in any case, the weed seed bank has been rarely studied in turfgrass. Mowing depletes the stored reserves in rhizomes of tall goldenrod [*Solidago altissima* L. (= *S. canadensis* L. var. *scabra* Torr. & A. Gray)], reducing biomass by 40% across 6 yr, although new rhizomes are longer and more numerous in mown plots than in unmown plots (Stoll et al., 1998). Side-oats grama [*Bouteloua curtipendula* (Michx.) Torr.] has less ability to reduce honey mesquite (*Prosopis glandulosa* Torr.) when it is mown (Bush and Van Auken, 1995). In an 18-yr experiment on roadsides, an increase from 1 to 2, and from 2 to 5 mowings per year caused a gradual change in species composition; for example, an increase in overall species diversity (Parr and Way, 1988). Removal of clippings led to an increase in plant species richness, probably because of the reduction in nutrient richness. Cessation of mowing of amenity grasslands led to high levels of primary productivity which resulted in high litter accumulation, reduction in belowground biomass, and colonization by forbs, particularly common sorrel (*Rumex acetosa* L.) (Dickinson and Polwart, 1982). Mowing every 2 wk generally eliminated field bindweed (*Convolvulus arvensis* L.) from buffalograss, bentgrass, and bermudagrass, but did not prevent colonization by dandelion, which developed stands of 800 to 1600 plants per square rod (32 to 63 plants m^{-2}) (Timmons, 1950).

In the absence of competition from turfgrass, when purple nutsedge is mown at 3.8 cm, and especially at 1.3 cm, there is a reduction of rhizome length, tuber number, and tuber size, compared with not mowing (Summerlin et al., 2000). In the same study, low mowing height (1.3 cm) of green kyllinga, also in the absence of competition, reduced shoot number and plant spread, and the same effects were noticed at a 3.8-cm mowing height, but not until the final evaluation. As noted earlier, a 2.5-cm mowing height increases green kyllinga, compared with a 5.0-cm mowing height, in a situation with competition from turfgrass (Lowe et al., 2000). An environmental stress such as close mowing may be harmful to weeds such as green kyllinga or even crabgrasses, but may be even more harmful to turfgrasses; therefore, weeds are given a relative advantage in a competitive environment.

Close mowing reduces the aboveground dry weight and root dry weight of kikuyugrass, but is inadequate to control it (Wilen and Holt, 1996). The regrowth potential of broad-leaved dock (*Rumex obtusifolius* L.) is very high, and it is not controlled by variation in mowing frequency (Niggli et al., 1993). These examples represent highly persistent perennial weeds. The selection pressure of mowing favors genetically shorter ecotypes, such as those of common plantain (*Plantago major* L.) (Warwick and Briggs, 1979) and annual bluegrass (Warwick and Briggs, 1978) and shows that weeds are genetically resilient.

Return of Turfgrass Clippings Sometimes Reduces Weeds. The handling of clippings gives contradictory results, depending on the situation. Return of clippings to creeping bentgrass increased annual bluegrass infestation 12% more than plots in which clippings were removed, apparently because of adding viable seeds (Gaussoin and Branham, 1989). Removing clippings reduced the number of viable seeds in the soil by 60%. In Texas, broadleaf weeds in St. Augustinegrass and bermudagrass were most numerous when mown with a mulching mower, with clippings recycled during mowing, and were least numerous where clippings were removed (Colbaugh and Knoop, 1989), based on a short-term, 9- to 17-wk study.

More often, weed reduction results from returning clippings. In Kentucky bluegrass, weed encroachment is less severe when clippings are returned (Haley et al., 1985), and this may be because of either a mulching factor or a fertilization factor resulting from recycled nutrients provided in the clippings. Treatments such as a high rate of N fertilization (300 kg^{-1} ha^{-1} yr^{-1}) that favor thatch development also result in a smaller weed population.

In a second study in Kentucky bluegrass, the return of clippings, as compared with clippings removal, is associated with fewer weeds (Heckman et al., 2000). In a mixed population of Kentucky bluegrass and perennial ryegrass in California, return of clippings reduced dandelion populations in one of two years (Harivandi et al., 2001). While the nutrient recycling hypothesis is reasonable, in conjunction with mowing height studies, the weed-reduction effect of returning clippings is also consistent with the hypothesis that whenever the soil surface is exposed, either because of low mowing, removal of clippings, or other factors, there are new canopy gaps for colonizing weeds to get established. While weeds are commonly defined to be plants that are not desirable in a particular place, many of the serious weeds in turfgrass are also annuals, first-stage successors capable of rapid growth in disturbed areas.

Fertilization

Higher Rate of N Fertilization Reduces Crabgrasses. Within the rates of fertilization reported, higher rates of N fertilization reduce crabgrass populations (Fig. 2A). This is based on studies of Kentucky bluegrass (Dunn et al., 1981; Johnson, 1981; Johnson and Bowyer, 1982; and Murray et al., 1983); tall fescue (Dernoeden et al., 1993; Voigt et al., 2001), and Chewings fescue (Jagschitz and Ebdon, 1985). Most of the studies involved no herbicides, or included a nonherbicidal control treatment; the 8-yr study by Murray et al. (1983) used only broadleaf herbicides in all plots, with or without supplemental herbicides.

In Kentucky bluegrass in Georgia, even the lowest level of crabgrass population, 32% cover, may be too great to avoid the use of herbicides (e.g., Johnson, 1981). In bermudagrass, although large crabgrass cover decreased slightly during 1 yr with increasing rates of N applied to bermudagrass (up to 400 kg N ha^{-1} yr^{-1}), crabgrass could not be acceptably reduced with N alone (Johnson and Burns, 1985).

Higher Rate of N Fertilization Reduces Other Weeds. After 4 yr of fertilization treatments, dandelion had higher cover when fertilized with 300 kg N ha^{-1} yr^{-1}

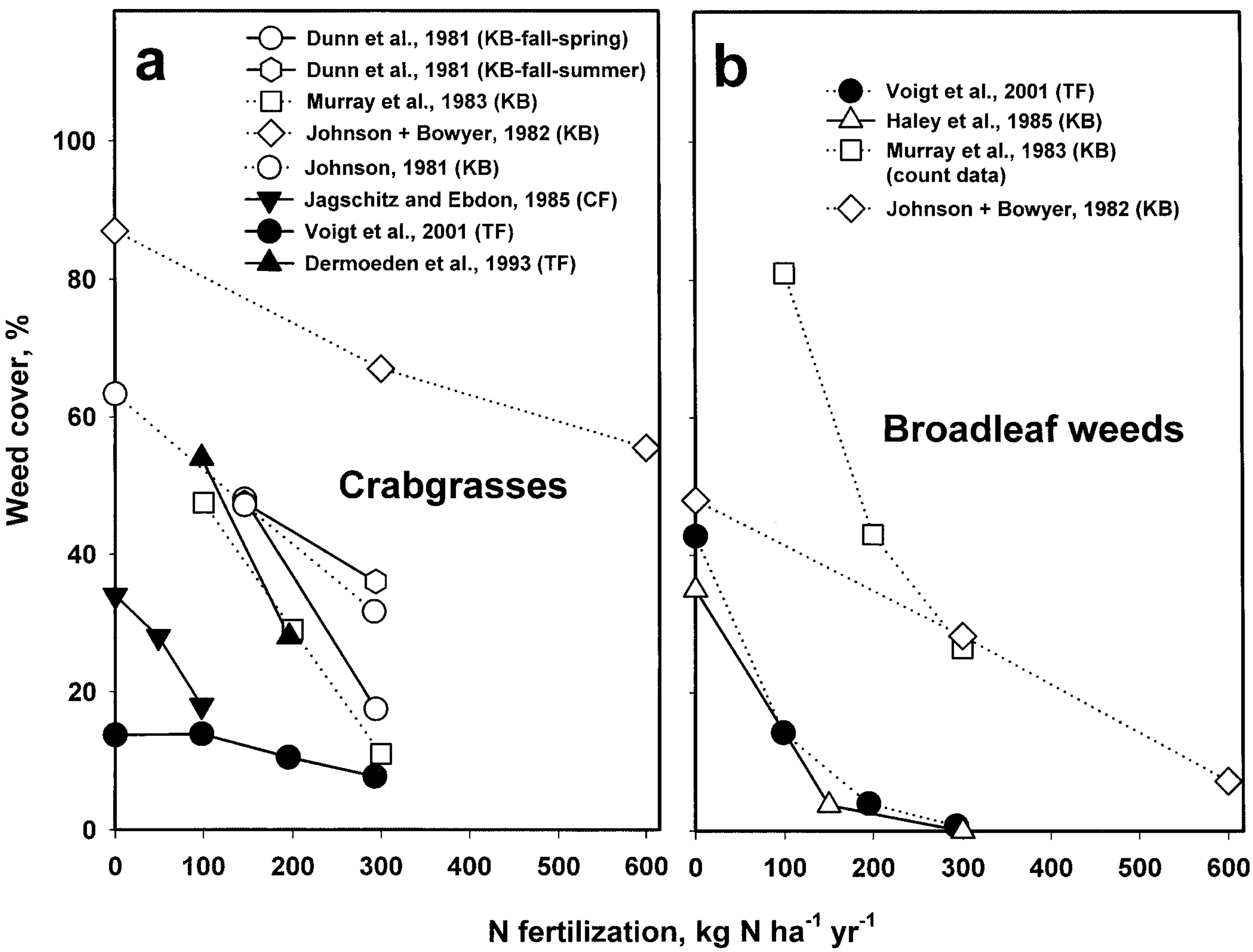

Fig. 2. Relationship of N fertilization rate to cover of crabgrasses [smooth crabgrass (*Digitaria ischaemum*), large crabgrass (*D. sanguinalis*), or unspecified (*Digitaria* spp.)] or broadleaf weeds, primarily dandelion (*Taraxacum officinale*), in cool-season turfgrass studies. Species of turfgrass are Kentucky bluegrass (KB, *Poa pratensis*), Chewings fescue (CF, *Festuca rubra* subsp. *fallax*), or tall fescue (TF, *F. arundinacea*). Data from Haley et al. (1985) were transformed from a 1-to-9 scale, with 1 = 0%, and 9 = 100%. Dandelion data from Murray et al. (1983) are counts per plot, not percentages.

than at 600 kg N ha^{-1} yr^{-1} (Johnson and Bowyer, 1982). Callahan and Overton (1978) reported 25% dandelion (cover?) fertilized with 95 kg N ha^{-1} yr^{-1}, compared with 4% at 190 kg N ha^{-1} yr^{-1}. Several studies have also reported on weed populations without specifying the species (Haley et al., 1985; Voigt et al., 2001), except that dandelion was predominant. Despite the sporadic evidence, higher N fertilization rate generally suppresses broadleaf weeds, the same as crabgrasses (Fig. 2B), probably because of stimulation of the turfgrass to grow more rapidly and be more competitive.

In the study by Murray et al. (1983), dandelion plants were counted rather than being expressed as a canopy cover percentage (Fig 2B). Canopy cover may be a more appropriate measurement for plants forming a continuous mat, such as crabgrasses, while counts may be a more appropriate measure for plants growing in separate rosettes, such as dandelion. In the study by Murray et al. (1983), high dandelion counts were observed after years of broadleaf herbicide application {2,4-D mixed with either silvex [2-(2,4,5-trichlorophenoxy)propionic acid] or dicamba (3,6-dichloro-2-methoxybenzoic acid)}, thus the management of dandelion by increasing N fertilization is necessary in spite of any herbicide use.

In weak Tifway bermudagrass turf, increasing N rate to 49 kg N ha^{-1} per month decreases green kyllinga spread by 40 to 50% (Lowe et al., 2000). Bermudagrass is a relatively quick-growing grass with maximum compound growth rate of 9.2% d^{-1} (Busey and Myers, 1979), and its growth responds strongly to high N fertilization when there is adequate temperature and sunlight. Lodge and Lawson (1993) observed the highest moss coverage in golf greens receiving low N fertilization rate.

Numerous pasture investigations have studied the maintenance of forage species under different fertilization regimes, and tended to support the turfgrass results. White clover is a desirable species to maintain in tall fescue pastures, though it is currently considered a weed in turfgrass stands. Fertilization with 135 kg N ha^{-1} yr^{-1} consistently reduces white clover, and the effect is more marked when N is applied in the early spring than later. Conversely, P and K fertilization occasionally increases white clover composition (Templeton and Taylor, 1966). The N effect in suppressing white clover is modified by clipping, as severe mowing results in higher percentages of clover (Robinson et al., 1952). In other ecological communities, plant species diversity drops when fertilizer is added (Rajaniemi, 2002), so this is consistent with the effect of a high rate N fertilization for enhancing monocultures of turfgrasses.

Fertilization when Turfgrass Is Not Growing Increases Weeds. The timing of N fertilization also matters; in Missouri there was less density of crabgrass when Kentucky bluegrass was fertilized on a fall–spring schedule than when fertilized on a fall–summer schedule (Dunn et al., 1981), and this might be expected knowing that the normal growth cycle of Kentucky bluegrass involves a slowing of growth in summer. In Maryland, the competitiveness of a primarily tall fescue sod crop is enhanced by two split applications of 73 kg N ha^{-1} applied in the fall, and competitiveness is decreased by spring fertilization (Hall, 1980). At the 2.5-cm mowing height, conducive to crabgrass, smooth crabgrass cover is 35% under the split fall fertilization schedule (September and October) compared with 67% crabgrass for a split spring schedule (April and May).

In contrast to tall fescue, a cool-season grass which performs poorly in response to warm-weather fertilization, zoysiagrass fertilized during the warm growing months gradually increases coverage. In competition in a mixture with 'Merion' Kentucky bluegrass in New Jersey, Engel (1974) showed that after 12 yr of fertilization at one time per year at 73 kg N ha^{-1}, 'Meyer' zoysiagrass content was 77, 75, and 77%, respectively, when the fertilization was in April, June, or August. In contrast, zoysiagrass was only 33 and 27%, respectively, when fertilized in September or October. Also in Missouri, N fertilizer applications later than September encouraged the proliferation of winter annual weeds, during the time that zoysiagrass would normally go dormant (Dunn et al., 1993).

In zoysiagrass in California, the higher the N rate, the greater the weed cover (Henry et al., 1989). In Missouri, the highest rate of 195 kg N ha^{-1} yr^{-1} applied to cultivated 'Meyer' zoysiagrass caused a very high population of henbit (*Lamium amplexicaule* L.), whereas plots receiving no N had a very high population of black medic (*Medicago lupulina* L.) (Weston and Dunn, 1985). These results may be explained by the fact that zoysiagrasses have a naturally slow growth rate (Busey and Myers, 1979). The only possible advantages that were mentioned for such a high N rate, compared with 98 kg N ha^{-1} yr^{-1}, would be in recovery from injury, or to bring thatch level back to protect against winter stresses (Weston and Dunn, 1985).

Annual Bluegrass May Be Increased by Higher Rate of N Fertilization. In initially perennial ryegrass sports turf maintained under different rates of N fertilization, annual bluegrass cover became 12, 17, and 34% for zero, medium, and high N fertilization, respectively (Adams, 1980); during the 22 weeks of the study, these corresponded to 0, 352, and 1248 kg N ha^{-1}. Lodge and Lawson (1993) showed that the rate of annual bluegrass infestation in a mixed fine turf stand of Chewings fescue [*Festuca rubra* L. var. *commutata* Gaudin [= *F. rubra* L. subsp. *fallax* (Thuill.) Hayek]}, highland bentgrass (*Agrostis castellana* Boiss. & Reut.), and colonial bentgrass (*A. capillaris* L.) is enhanced by increased N input. In only 1 yr out of three, Gaussoin and Branham (1989) observed an increase of annual bluegrass at 293 kg N ha^{-1} yr^{-1}, compared with 98 kg N ha^{-1} yr^{-1}, and they disagreed with the conclusion of a N fertilization effect on increasing annual bluegrass populations. Bentgrass population increased during 3 yr when N was withheld, under conditions of annual bluegrass competition (Dest and Guillard, 1987). In carpetgrass, Bush et al. (2000) observed a linear increase of annual bluegrass infestation in carpetgrass with increasing N fertilization when mown at a 3.8-cm height.

Other Nutritional Relationships (P, K, Ca, and S). One of the earliest demonstrations of nonherbicidal management of turf weed populations was the use of fertilizers to reduce the colonization of turf areas by annual bluegrass (Sprague and Burton, 1937). A high level of S fertilization (168 kg S ha^{-1} yr^{-1}) greatly reduces annual bluegrass in creeping bentgrass, especially when P is not applied (Goss, 1974). It had been thought that the lowered soil pH resulting from applied S was responsible for favoring creeping bentgrass and restricting annual bluegrass; alternatively, that applied S may compensate for a deficiency of S occurring at a high rate of N application. Subsequently, it was shown (Kuo, 1993) that the effect of S in reducing annual bluegrass is even more indirect, that the lowered soil pH had reduced the availability of P, a nutrient to which annual bluegrass is more responsive than is creeping bentgrass (Kuo, 1993). An even stronger effect is the differential response to Ca between the two grasses. Adequate soil Ca availability is necessary to maintain bentgrass growth, particularly in acid soil.

In a long-term study, at the 140-yr-old Park Grass Experiment at Rothamsted, UK, abundance of dandelion increased 17- to 20-fold because of K fertilization, and a similar relationship occurs in lawns in Minnesota (Tilman et al., 1999). One of the most unusual uses of fertilizers to manage weeds involves the application of nutrients as herbicides to creeping bentgrass fairways. Annual bluegrass is reduced 65% in plots treated with 1.68 kg Fe ha^{-1} and 1.68 kg Mg ha^{-1} applied to the foliage (Bell et al., 1999). The effect may be because of the accelerated photorespiration caused in annual bluegrass from the added nutrients. Before the 1940s, the limited chemical management of weeds involved the use of fertilizers such as urea (DeFrance et al., 1947), but applied in this way these compounds are herbicides and outside the definition of cultural management.

Irrigation

Irrigation treatment, daily vs. evapotranspiration (ET) replacement, had no effect on smooth crabgrass or dandelion incidence in perennial ryegrass (Jiang et al., 1998). The coverage of annual bluegrass seeded into creeping bentgrass was not affected by irrigation amount; that is, 100% of ET replacement, compared with 50% of ET (Bell et al., 1999). In the latter studies, the driest treatment involved irrigation up to three times per week, which may not have been particularly harsh. No effect of irrigation regime on annual bluegrass was observed by Lodge and Lawson (1993). Daily irrigation at 75% of open Class A (Fischer and Nel, 1990) pan evaporation (Ep) resulted in more annual bluegrass than in plots irrigated three times per week at 110% of open pan evaporation (Gaussoin and Branham, 1989). The authors concluded that the higher frequency of irrigation, by maintaining sufficient soil moisture in the upper profile, is more important than irrigation amount for annual bluegrass seedling recruitment. In bermudagrass turf, irrigation at the approximate rate of open pan evaporation is associated with the highest density of annual bluegrass, whereas lesser rates of irrigation have less or no annual bluegrass (Youngner et al., 1981).

There is less weed colonization by spotted spurge, creeping woodsorrel (*Oxalis corniculata* L.), and smooth crabgrass in Kentucky bluegrass and tall fescue irrigated by a subterranean system, compared with overhead (Gibeault et al., 1985). This is consistent with the idea that when there is a moist soil surface, weed seeds can germinate. In the same study, there was more creeping woodsorrel in perennial ryegrass and tall fescue irrigated at 100% of ET, compared with 60%. 'Prairie' buffalograss irrigated at 115% of Class A Ep is significantly encroached by annual bluegrass, bermudagrass, St. Augustinegrass, and dallisgrass (*Paspalum dilatatum* Poir.) (Qian and Engelke, 1999). The latter study also showed that tall fescue irrigated at >100% Ep is colonized by Texas bluegrass (*Poa arachnifera* Torr.) and Kentucky bluegrass, while zoysiagrass irrigated at <39% Ep is severely colonized by prostrate spurge and spotted knapweed [*Centaurea maculosa* auct. non Lam. (= *C. biebersteinii* DC.)]. As indicated earlier, in the comparison of *Festuca* cultivars and species, drought can lead to loss of stand, followed by weed colonization (Dernoeden et al., 1994).

Weed seed dormancy is often broken by alternating cycles of temperature and moisture (Martínez-Ghersa et al., 1997); therefore, wetting and drying cycles that result from irrigation practices could facilitate weed seed germination.

Irrigation management is used on golf courses to accelerate spring transition from overseeded perennial ryegrass back to hybrid bermudagrass. This is effective in South Florida, which has an annual spring dry season from March to May.

Cultivation

Goosegrass is prevalent in compacted areas such as alongside cart paths (Busey, 1999). This may be because of stresses on the turfgrass, such as mechanical impedance to root growth, unfavorable conditions in the soil atmosphere, or reduced water and nutrient availability. Goosegrass roots grow well under conditions of oxygen diffusion $< 5 \times 10^{-8}$ g cm^{-2} min^{-1}, but Kentucky bluegrass root growth is reduced or stopped when oxygen diffusion is between 5 and 9×10^{-8} g cm^{-2} min^{-1} (Waddington and Baker, 1965). Core aeration is the procedure usually used to alleviate compaction. During 3 yr, Lodge and Lawson (1993) observed progressively higher shoot density of annual bluegrass in greens areas constructed of soil compared with sand and a USGA-specification construction. This may have been because of either chemical or physical soil properties.

Zoysiagrass which receives aeration treatments, but no N fertilization, can develop a high population of black medic (Weston and Dunn, 1985). In the absence of herbicides, vertical mowing (verticutting) of bermudagrass increases populations of large crabgrass, when performed in summer (Johnson, 1979). But when the same vertical mowing treatment is performed in winter, there is an increase of common chickweed, henbit, and brome grass (*Bromus* spp.).

In North Carolina there was no cultivation treatment that consistently enhanced the natural transition of perennial ryegrass to bermudagrass (Horgan and Yelverton, 2001). A concern with cultivation is compatibility with preemergence herbicides. One or three instances of core cultivation does not influence preemergence herbicide activity (Branham and Rieke, 1986; Johnson, 1987). Because of the adverse effects on stand density, which could lead to weed colonization, secondary cultural practices such as core aeration and vertical mowing were determined not advisable for routine maintenance of home lawns (Carrow et al., 1987).

CONCLUSIONS

Synthesis of Cultural Management Research

Crabgrasses can be managed in lawns of some cool-season turfgrasses by mowing relatively high, which results in no more than 15% infestation (Fig. 1), but a similar effect on other weeds has been reported so sporadically (three reports on different weeds) as to provide no confidence. For effective cultural management of crabgrasses, and depending on other environmental factors, a 4- to 6-cm mowing height is appropriate for Kentucky bluegrass, and a 6- to 8-cm height is appropriate for tall and fine fescues. Crabgrass reduction is accomplished also by fertilizing cool-season turfgrasses with relatively high rates of N, for example, 100 to 300 kg N ha^{-1} yr^{-1} (Fig. 2A), but usually there remains >15% crabgrass, which probably would be unacceptable to most users.

Dandelion and mixed broadleaf weed populations are similarly reduced by fertilization with at least 100 to 300 kg N ha^{-1} yr^{-1}. On the basis of sporadic reports, this is a strong relationship (Fig. 2B). In studies on four different cool-season turfgrass species, high rate of N fertilization contributes to high infestation by annual bluegrass. High weed infestation occurs in well-fertilized zoysiagrass. A high rate of N fertilization increases weed infestations when a turfgrass is dormant (tall fescue or Kentucky bluegrass in summer, and zoysiagrass in winter). Severely damaging stress, such as insects, diseases, nematodes, unnecessary aeration or vertical mowing, or drought damage, increase weed infestation. Frequent irrigation is associated with high populations of annual bluegrass and occasionally other weeds such as dollarweed (*Hydrocotyle umbellata* L.) (2001, unpublished data). The use of genetically adapted turfgrass species and cultivars and their timely establishment often reduces weeds, even in the absence of herbicides.

Cultural Management vs. Herbicides

Direct comparison of individual cultural management variables vs. herbicides is available in few cases. Smooth crabgrass cover in tall fescue was 2.9% when mown at a 8.8-cm height and no preemergence herbicide was applied, whereas crabgrass cover was between 5.0 and 13.5%, depending on which preemergence herbicide was applied, when mown at a 5.5-cm height (Dernoeden et al., 1993). Smooth crabgrass infestation in Chewings fescue showed a negative relationship with mowing height and N fertilization rate, and the effects of cultural management improved with time (Jagschitz and Ebdon, 1985). For example, during 5 yr without herbicide, plots mown at 5.7 cm had a reduction of smooth crabgrass, from 20% down to 4%, across 5 yr. In contrast, plots mown at 3.2 cm and treated with preemergence herbicide only at the beginning of the study had an increase from 2% smooth crabgrass the first year to 37% in the fifth year. High rate of fertilization, at least 200 kg N ha^{-1} yr^{-1}, was partially effective at dandelion suppression in bermudagrass, although dandelions were more effectively reduced at a low pH (5.0), adjusted by tilling in elemental sulfur (Johnson and Burns, 1985). Adjustment of pH was comparable with the only effective herbicide, oxadiazon {3-[2,4-dichloro-5-(1-methylethoxy)-phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3*H*)-one}, in managing dandelion.

Cultural management of weeds in turfgrass is reportedly a gradual process, with reduction in weed populations sometimes taking place across years. In comparison, chemical management of weeds is often successful in a matter of weeks or months, ignoring that weed populations often recur in the same area, and may require successive annual chemical treatment to the same area.

Besides the thinness of the published data, there are situations when cultural management is clearly inadequate. For example, Johnson and Burns (1985) reported a case where large crabgrass in bermudagrass could not be controlled with either pH modification or fertilization, and in another report crabgrass infestation of Kentucky bluegrass was unacceptable without the use of herbicides (Johnson, 1981). Even when cultural management adequately controls weeds in turfgrass, the effect of raising mowing height might be so unacceptable for a particular turf use that it would not be feasible. Likewise, when cultural practices require additional expenditures or cause negative environmental effects, such as for extra N fertilization, it may be more cost effective to rely on herbicides. Potential environmental effects from a high N fertilization rate could include nitrate leaching and runoff, the mining of fossil fuel to produce the fertilizer, and the additional mowing energy requirement which results from additional N fertilization (Fluck and Busey, 1988).

Conversely, herbicides cannot be relied on exclusively to manage weeds because there are cases where there is no known selective herbicide for suppressing or killing a particular weed, or where an overused herbicide has selected for genetically resistant weed populations. In other cases, successive annual herbicide treatments cause a shift in weed populations, so that minor weeds change into major weeds (Johnson, 1982).

An integrated approach is the most likely solution to effectively manage weeds in turfgrass. Cultural practices and chemicals can complement each other and give flexibility to decision making. As an example, cultural management might provide a first defense, and herbicides would be available, if needed, as an alternative if unexpected seasonal conditions caused more weed infestation than expected. However, in the case of preemergence herbicides, the choice to apply must be made early, therefore the decision to emphasize cultural management, such as fertilization, vs. preemergence herbicides must be done in anticipation of weeds. Knowledge of specific conditions and mechanisms is essential in integrated management of weeds in turfgrass.

Practical Relevance

Most studies of cultural management are long-term, based on multiple-year observations in field environments simulating interspecies competition. This is appropriate because lawns, golf courses, and sports fields are normally cultured as perennial ecosystems. No study has reported on the effects of shade or traffic stress as aspects of cultural management of weeds. Both shade and traffic commonly occur in turfgrass areas, and are associated with weed problems. No study considered the patchiness of weed populations within an area, for which more localized cultural management might be appropriate. No study considered the border effects and localized disturbances that occur from discontinuity within turfgrass areas, or at a single time, that could be a source of weed colonization. For example, is a single event of scalping otherwise tall-mown turfgrass more significant than continuous low mowing? Except for one roadside study, there was no consideration of mowing frequency effects on weeds in turfgrass.

Other cultural methods, for which no turfgrass research could be found, involved weed exclusion by possible restriction of traffic, wind, water, or other means of weed seed dispersal. Mechanical- and hand-pulling of weeds, which is occasionally used in practice, has not been studied. The use of fire, either localized or through prescribed burning, is not mentioned except in seed production (e.g., Mueller-Warrant et al., 1994), even though fire has been used with grazing as the first cultural management tool by which humans affected grasslands.

The effects of combinations of mowing height and N fertilization rate were often not presented. Either one factor was studied at a time, or the interaction of main effects was not statistically significant. The omission of factor combinations is statistically correct, as the effect of mowing height and N fertilization rate combinations can be predicted from the main effects. Nevertheless, it would be more understandable for the purpose of making recommendations to turfgrass managers to report the specific result of factor combinations, as an example of the results that they might expect by following combined recommendations.

More research is needed on the cultural management of weeds in warm-season turfgrasses and the consequences of long-term strategies for weed management. More research is needed on new turfgrass species and cultivars before they are widely adopted in the market. Serious weed problems may occur in cultivars and species used outside their region of adaptation.

Scientific Relevance

Any stress that defoliates the turfgrass and exposes the soil to sunlight would be expected to provide canopy gaps for colonization from a persistent seed bank, representing annual species. As an example, goosegrass is a major problem of bermudagrass turf in warm temperate and subtropical regions. In a closely and periodically mown stand of bermudagrass, the presence of fluctuating temperatures and possibly light are believed to be important stimuli for goosegrass seed germination (Nishimoto and McCarty, 1997). A distinction must be made between the type of weed, that is, ruderal species capable of colonizing canopy gaps, vs. *closed-turf* species. In an experiment involving artificial canopy gaps, it was shown by Fenner (1978) that the relative growth rates of ruderal species were much more reduced in tall (8-cm mowing height) turf compared with short turf (1-cm mowing height), and closed-turf weeds were not so strongly affected. There have been few studies reporting the LAI of turf canopies. Bentgrass and zoysiagrass greens were reported to have LAI values of ≈2.0, with the value reduced ≈10% following mowing (Agata et al., 1989). Kopec et al. (1987) reported a range of LAI values for tall fescue, from ≈1.0 to 3.5, and also showed how LAI could be measured quickly and nondestructively.

To predict the long-term benefits of cultural vs. chemical management of weeds and their integration requires knowing both the persistence of consecutive annual herbicide applications to the same ground, as well as the weed seed bank in soil, resulting from both chemical and cultural methods. With two exceptions (Lush, 1988; Gaussoin and Branham, 1989), seed bank data is not available from turfgrass areas. A study of an *Agrostis–Festuca* pasture showed that without input of fresh seed, the grass seed bank declines 27% yr^{-1}, compared with 16% yr^{-1} for dicotyledonous species (Williams, 1984). In a field study, the decline of viable weed seeds under a grass sward during 20 yr was much slower, and did not eradicate the seeds of even the most rapidly declining species (Chancellor, 1986). In the case of annual bluegrass in a golf green, the seed bank is high and exhibits high seasonal fluctuation (Lush, 1988), which could be important in identifying when turfgrass is particularly vulnerable to colonization.

Many ecological studies are directed to understand factors enhancing species diversity; therefore, the emphasis on uniformity in turfgrass, even monocultures, is a converse application of the same concept. In either case, the mechanisms are only partially understood. If we could understand better the mechanisms for the cultural management of weeds of turfgrass, it might be possible to make reasonable inferences for an integrated best management system for weeds in turfgrass.

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