UNIVERSITY OF
FLORIDA

Institute of Food and Agricultural Sciences
Everglades Research and Education Center, Belle Glade

P.O. Box 8003
Belle Glade FL 33430-8003
Tel. (561) 996-3062 Ext. 111
Fax (561) 996-0339
E-Mail ghs@gnv.ifas.ufl.edu

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Ms. Marlene J. Czerniak, Project Manager
Division of Agricultural Environmental Services
Florida Department of Agriculture and Consumer Services
3125 Conner Boulevard, Suite 126
Tallahassee, FL 32399-1650

Dear Ms. Czerniak:

Following reviews by Dr. Cisar (UF/IFAS-Ft. Lauderdale) and Dr. Sartain (Soil and Water Science Department, University of Florida), the final report for our FDACS-funded project "Development of Best Management Practices for Reducing Ground Water Nitrogen Loading From Turfgrass Areas" is enclosed, along with a disk copy of the report and of the literature search program and database. I am sending Mr. Eric DeHaven a copy of the report as well. Dr. Cisar and I will be available to assist in further developing the turfgrass BMPs if you so wish.

Sincerely,

George H. Snyder
Distinguished Professor - Soil and Water Science

FINAL REPORT

DEVELOPMENT OF BEST MANAGEMENT PRACTICES FOR REDUCING GROUNDWATER NITROGEN LOADING FROM TURFGRASS SOILS

George H. Snyder[1] and John L. Cisar[2]
University of Florida
[1] Everglades Research and Education Center
P.O. Box 8003, Belle Glade, FL 33430
[2] Ft. Lauderdale Research and Education Center
3205 College Avenue, Ft. Lauderdale, FL 33314-7799

EXECUTIVE SUMMARY

The project was designed to suggest Best Management Practices (BMPs) and Interim Measures (IMs) for nitrogen fertilization of turfgrass that will protect groundwater by maintaining nitrogen (N) in percolate below 10 mg L^{-1}. Citation information for 121 publications dealing with turfgrass nitrogen fertilization in Florida and related publications were located and loaded into a DOS-based searchable database computer program, and hard copies of the publications were assembled. Following a review of this information, BMPs were developed for golf courses. These BMPs were discussed at a number of golf course superintendent meetings and were published in industry trade magazines. We believe these BMPs will be effective, and will be acceptable to the golf course industry for course maintenance. In general, less N is used on athletic fields than on golf fairways, and no N leaching research was located that directly pertains athletic fields. However, by combining University of Florida/IFAS (UF/IFAS) recommendations for N fertilization of athletic fields with the proposed BMPs for golf courses, a BMP for athletic field N fertilization can be proposed. Little or no N fertilization is needed for muck-grown sod, but research is needed for mineral-soil grown sod to provide BMPs for N fertilization. Although no research was found specifically relating to N leaching in St. Augustinegrass home lawns, IMs can be developed using UF/IFAS N fertilizer recommendations along with the portions of the golf course BMPs relating to methods of application, irrigation, and enhancing root systems. Never-the-less, research is needed to verify the IMs in regard to subsequent N leaching, and to deal with special home lawn issues such as the application of water-soluble N by lawn service companies. Studies on fertilization of "ultradwarf" bermudagrasses and associated N leaching, and on minimizing N leaching during golf course fairway grow-in, also are warranted in order to develop BMPs for these situations.

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OBJECTIVE 1. Collect and review all Florida literature relating to nitrogen (N)leaching in turfgrass and pertinent literature from other regions.

One hundred and twenty-one literature citations were obtained, assigned a reference number, and compiled into three loose-leaf notebooks. The citations were loaded into a DOS-based searchable database computer program called "3 by 5". Through the use of this program, papers, and their reference number, can be located on the basis of key words. This literature collection was referred to in satisfying the remaining objectives. A disk-copy of the literature citations is included with this report. The collection of full papers will be maintained by Snyder and Cisar.

OBJECTIVE 2. Develop Best Management Practices (BMPs) for maintaining bermudagrass on golf courses, athletic fields, and for growing St. Augustinegrass sod on muck.

GOLF COURSES.

The majority of the literature citations that dealt with a specific grass dealt with bermudagrass (23 citations). Only nine citations primarily involved St. Augustinegrass, and none primarily involved bahia- grass, centipedegrass, or zoysiagrass. Many of the citations relating bermudagrass and St. Augustinegrass did not specifically deal with N leaching, but rather discussed N fertilization for turfgrass quality, growth, and other measures of performance. However, enough information was available to develop tentative BMPs for the use of bermudagrass on golf courses (Fig. 1).

The University of Florida currently recommends up to 24 pounds N per 1000 sq. ft. per year for golf greens, and up to 6 pounds for fairways (Sartain et al., 1999). The BMPs developed herein limit N on greens and tees to 2 pounds per month, and N on fairways and roughs to 1 pound per month.

The objective of the BMP for golf courses is to maintain N in percolate below 10 mg L^{-1}. A study by Cisar et al. (1990) demonstrated that N leaching remained below this value following water-soluble N applications of 2.5 g m^2 (ca. 0.5 pounds of N per 1000 square feet), but not at 5.0 or 10.0 g N m^2.

There is abundant evidence that controlled-release fertilizers reduce N leaching in turfgrass (Sartain, 1990; Snyder et al., 1980; Snyder et al. 1984), and the BMPs stipulate the use of such sources when N fertilization exceeds 0.5 pounds per application. When properly used fertigation (the application of fertilizer through the irrigation system) has been shown to reduce N leaching and effectively simulate the use of controlled-release fertilizers while at the same time permitting the use of the less costly soluble N sources (Snyder et al., 1989). Therefore, the BMP permits the use of fertigation to apply small amounts (less than 0.5) of N on a frequent basis. In practice, fertigation generally will be used to apply N at less than 0.1 pounds per application.

Excessive irrigation contributes to N leaching (Snyder et al., 1984). The BMPs limit irrigation to the amount required to replace soil moisture. Since N leaching can be reduced both by reducing percolation and by reducing the concentration of N in the percolate, it seems self evident that any measures that encourage abundant, deep, active root systems will also decrease N leaching. Bowman et al. (1998) demonstrated an inverse relationship between root mass and N leaching. For this reason, the BMPs encourage cultural practices that enhance turfgrass root systems, within the confines of desired turfgrass playability and legal use of agrichemicals. Root-damaging conditions such as soil compaction, soil layering (including excessive thatch), poor aeration, root-feeding insects and nematodes, root diseases, inadequate soil depth, and localized dry spots should be avoided.

Considerable effort was made to expose golf course superintendents to the proposed BMPs, and to solicit their reaction. A slide presentation explaining the Nitrate Bill, its implications for golf course superintendents, and the proposed BMPs was presented at a number of meetings of golf course superintendents, including meetings of the Everglades, Seven Rivers, Treasure Coast, West Coast, Ridge, Palm Beach, and South Florida chapters of the Florida Golf Course Superintendents Association. The information was presented at a United States Golf Association seminar in North Palm Beach, and at University of Florida Turfgrass Field Days in Gainesville, Milton, and Ft. Lauderdale. A written summary of the BMPs was provided to attendees at each meeting. In addition, the information was published in the industry trade magazines the Florida Green (Snyder and Cisar1998a) and the Florida Turf Digest (Snyder and Cisar, 1998b). In all cases, the audience was encouraged to provide feedback to the authors. The authors also met with Dr. Jerry Sartain, University of Florida Soil and Water Science Department, in Gainesville to discuss the BMPs. The only concerns expressed were that a) additional water-soluble N fertilization may be desired for a short time in the spring when transitioning from a winter-overseeded grass to the summer bermudagrass in order to encourage bermudagrass growth, b) the BMPs are not appropriate for growing in a new golf course, and c) the new "ultra-dwarf" varieties being marketed for use on putting greens may have N requirements different from the traditional 'Tifgreen' and 'Tifdwarf' cultivars.

The proposed BMPs were not developed for growing in a golf course, and should not be applied at that time. FDACS funded Dr. Sartain to investigate the grow-in period, and can look to him for guidance on that issue. The term "ultra-dwarf" has been given to new bermudagrass varieties having growth characteristics that permit extremely close (< 0.125 inch) mowing. Nitrogen fertilization requirements, and associated N leaching, have not been well documented for the ultra-dwarfs in Florida, and there is no consensus on this issue. Opinions range from much more to much less N being needed. Regarding fertilization of ultra-dwarfs, and especially the temporary use of additional soluble N during the so-called transition period, it should be noted that in-so-far as fertilization of putting greens is concerned, greens generally constitute less than 3% of the golf course area, which often is less than that of unfertilized or lightly-fertilized roughs and out-of-bounds areas. While considerable research has been directed toward golf green fertilization and associated N leaching, these efforts may be disproportionally large in comparison the actual impact of greens fertilization on the entire golf course "watershed".

There always is potential for excessive N leaching in irrigated turfgrass grown on sand soils, and nitrate-N concentrations exceeding 10 mg L^{-1} in percolate below golf turf have been observed both in research plots and on operating golf courses. However, in a study that included 12 golf courses in Florida, Cohen et al. (1999) observed nitrate-N exceeding 10 mg L^{-1} in less than 4% of ground water samples, and theorized that most of these were due to prior agricultural use. In monitoring percolate water on several Florida golf courses, Snyder and Cisar (1999) observed considerable nitrate-N leaching during the "grow-in" period, but nitrate-N in percolate generally remained below 10 mg L^{-1} thereafter. We believe that nitrate-N in percolate from golf courses will generally remain below 10 mg L^{-1} if the proposed BMPs for golf courses are followed, and that they will pose no undue management hardship on the industry.

ATHLETIC FIELDS

None of the references on N leaching in the developed data base specifically refer to athletic fields for football, soccer, baseball, or other non-golf field sports. The fields used for these purposes generally have bermudagrass, although some of the lower-maintenance fields may be bahiagrass. St. Augustinegrass is rarely used. Although studies on N leaching in athletic turf could not be obtained, McCarty and Cisar (1995a) have presented fertilization guidelines for athletic fields (Table 1). These guidelines specify from 5 to 7 pounds N annually per 1000 square feet for bermudagrass, depending on location in Florida and overseeding, and 4 pounds of N annually for bahiagrass. They also limit per-application N fertilization to 1 pound of controlled-release N or 0.5 pounds of water soluble N per 1000 square feet. Thus, the fertilizer rate and source recommendations are within the limits of the proposed BMPs for golf courses. However, the limitation of 1 pound of N from a controlled-release source probably is unwarranted when N fertilization is recommended in successive months, since good controlled-release N sources can be applied at higher rates without releasing excessively high amounts of water-soluble N over short time periods. The golf course BMP for N rates limited the amount of N "that will become available in any given month" (Fig. 1), rather than the actual amount of N applied, to take advantage of the properties of controlled-release N sources. A similar strategy seems appropriate for athletic fields. With this modification, the recommendations in Table 1, plus the golf course recommendations relating to methods of application, irrigation, and enhancing root systems, could form the basis of a BMP for athletic fields.

ST. AUGUSTINEGRASS SOD PRODUCTION ON MUCK

There are no references in the database to studies of N leaching during sod production on organic soils (muck, or Histosols). Based on the work of Cisar et al. (1992), the N fertilization recommendations presented by McCarty and Cisar (1989) are valid only for mineral soils. Cisar et al. (1992) determined that no N was needed for growing sod on organic soils in the Everglades. In practice, a small amount of N may be applied shortly prior to harvest to cosmetically improve the grass prior to marketing, and some growers no doubt fertilize with N in spite of research data indicating that such fertilization is unnecessary. However, in the Everglades Agricultural Area (EAA), where most of the muck-grown sod is produced, most N in water emanating from sod fields will come from decomposition of the organic soils (Tate, 1976), and not from N fertilizations. Since there is a virtually impermeable barrier of limestone underlying the EAA (Healy, 1975), none of the outflow enters the underlying aquifer, and a considerable amount of denitrification occurs (Terry and Tate, 1980). In the EAA at least, the only BMPs may be to not use N fertilizer for sod production, although the 2.5 pounds per 1000 square feet total annual application recommended by Sartain (1998) probably will not greatly affect N leaching, and to maintain water tables as high as possible (12 to 18 inches depth) to minimize decomposition of organic soil, and subsequent excessive N mineralization. The same techniques should be beneficial for reducing nitrate-N leaching during sod production on organic soils outside of the EAA where such leaching may threaten groundwater to a greater degree. However, since the research is inadequate to verify these measures, they probably should be considered to be interim measures, at best.

OBJECTIVE 3. Develop Interim Measures (IMs) for home lawns and large-scale commercial areas (industrial parks, airports, cemeteries).

In Florida, home lawns generally utilize St. Augustinegrass, although bahiagrass also is used. Industrial parks, airports, and cemeteries are most likely to use bahiagrass, although St. Augustinegrass also may be used. The data base contains no N leaching data from Florida on these grasses. However, following the University of Florida home lawn guidelines for N fertilization of St. Augustinegrass (McCarty and Cisar, 1995b) and bahiagrass (McCarty and Cisar, 1997), as are presented in Tables 2 and 3, respectively, should maintain nitrate-N concentrations in percolate below 10 mg L^{-1}, except possibly when 1 pound of water-soluble N is recommended in one application (Footnote 4, Table 3), or when a controlled-release N source is not specified as part of a "complete" fertilizer (Footnote 1, Table 2; Footnote 2, Table 3). Thus these tables, plus the golf course recommendations (Fig. 1) relating to methods of application, irrigation, and enhancing root systems, could form the basis of BMPs for home lawns and large-scale commercial areas.

OBJECTIVE 4. List gaps in research that must be filled to provide BMPs or IMs for such turfgrass scenarios as bermudagrass and St. Augustinegrass sod production on sand, winter overseeding, effluent use, new N sources, lawn service companies using liquid fertilizers, optimum ratio of water-soluble to controlled-release fertilizers, compost use for turfgrass, and to verify interim measures for St. Augustinegrass and bahiagrass.

We found no N leaching data directly relating to any of the items listed in Objective 4 for Florida. The authors currently are obtaining some N leaching data on compost-amended turfgrass plots, and on effluent-irrigated golf turf that is winter overseeded. To prioritize the needed research, it is suggested that the first priority be studies on fertilization of St. Augustinegrass managed as a home lawn, because the acreage of home lawns exceeds that of all other uses, combined (Hodges, et al., 1994). Since St. Augustinegrass generally is fertilized more heavily than bahiagrass, the former would have the greater priority. Nitrogen fertilization studies on St. Augustinegrass that also included an examination of N leaching could evaluate N sources, methods of fertilizer application, and ratios of water-soluble N to controlled-release N. These data would be useful for verifying IMs, and for providing a firm basis for making BMPs.

Nitrogen-leaching studies also should be performed on sand-grown sod. Although the total acreage of this crop is not great compared to that of the other turfgrass sectors (Hodges et al., 1994), the need for rapid grow-in and the high proportion of the soil surface that is uncovered by turf during a portion of the production cycle suggests that N leaching could at times be a problem and percolate could exceed 10 mg L^{-1}. In particular, the research could investigate application methods that direct N fertilizers to the grassed portions of the sod fields, and minimize N fertilizer application on bare areas.

With the development of ultra-dwarf bermudagrass varieties, and their commercialization during the past several years, research needs to be conducted on the N requirements of these grasses when used for golf greens in Florida, and on the subsequent N leaching. The proposed golf course BMPs may not be appropriate for ultra-dwarf bermudagrasses, and these grasses were not used in past research on N leaching. However, since greens constitute a relatively small portion of a golf course, the priority for this research may not be high relative to the home lawn situation. FDACs has sponsored research on golf green grow-in, but the grow-in of fairways occurs on a much greater acreage and needs attention from researchers to minimize N leaching from fairways during this period.

Fig. 1. BMPs FOR MINIMIZING NITRATE-NITROGEN LEACHING ON GOLF COURSE TURF

OVERVIEW. The principle factors that can be implemented to minimize nitrate-N leaching on golf courses are 1) nitrogen rates, 2) nitrogen sources, 3) methods of application, 4) irrigation practices, and 5) enhancement of root growth and activity. Some of these factors are interrelated.

SPECIFIC PROPOSALS.

NITROGEN RATES: (All fertilization rates are presented as pounds of N per 1000 square feet. Multiply by 43.56 to convert to pounds per acre)

A. Nitrogen fertilization of greens and tees should not exceed 2, and that for fairways and roughs should not exceed 1 (pound/1000 sq. ft.) that will become available in any given month.

B. Water soluble N should not exceed 0.5 per application.

C. Nitrogen in irrigation water, such as that in effluent, should be credited towards the maximum monthly allowance.

NITROGEN SOURCES:

A. Controlled-release N sources should be used when more than 0.5 needs to be applied in a single application. These sources may be indicated on the Florida fertilizer label as 'water-insoluble N', or as 'controlled-release' N.

METHODS OF APPLICATION:

A. Fertigation may be used to apply small amounts (less than 0.5) of N on a frequent basis.

B. Nitrogen may be applied in sprays either for foliar applications or for ground applications, but the rate of N application should not exceed 0.5.

IRRIGATION PRACTICES:

A. Irrigation amounts should not exceed the amount needed to restore soil moisture to field capacity, plus the percent irrigation efficiency of the irrigation system in use.

ENHANCEMENT OF ROOT GROWTH AND ACTIVITY:

A. Cultural practices should be employed to enhance turfgrass root systems, within the confines of desired turfgrass playability and legal use of agrichemicals. Root-damaging conditions to be avoided include soil compaction, soil layering (including excessive thatch), poor aeration, root-feeding insects and nematodes, root diseases, inadequate soil depth, and localized dry spots.

Table 1. Suggested fertilization schedule for athletic fields.(from McCarty and Cisar, 1995)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Overseeded bermudagrass with ryegrass and/or south Florida bermudagrass fields	--	N[1]	--	C[2]	--	N	--	C	N	C	--	C
Non-overseeded north Florida bermudagrass fields	--	--	--	C	--	N	--	C	N	C	--	--
Bahiagrass/St. Augustine fields	--	--	--	C + Fe[3]	--	N	--	N	--	C + Fe	--	--

1 Application frequency will be determined by nitrogen source used. A slow release source such as IBDU or sulfur coated urea should be applied at 1 pound actual nitrogen per 1000 sq. ft. (i.e., 3.2 pounds 31-0-0 per 1000 sq. ft. or 140 pounds per acre). A quick release nitrogen source such as ammonium nitrate should be applied at 1/2 pound actual nitrogen per 1000 sq. ft. every 2 to 3 weeks (1.5 pounds 33-0-0 per 1000 sq. ft. or 66 pounds per acre) during those months indicated with N. Be sure to irrigate quick release nitrogen sources immediately after application to minimize turf burn.

2 Use a complete (C) fertilizer ratio (e.g., 412 or 312) at 1 pound nitrogen per 1000 sq. ft. (i.e., 6.25 pounds 1648 per 1000 sq. ft. or 272 pounds per acre).

3 Yellow appearance may indicate iron (Fe) or manganese deficiency due to low soil temperatures, excessive soil pH (>7.0), or excessive soil phosphorous levels. Spray iron (ferrous) sulfate (2 oz. in water per 1000 sq. ft. or 87 oz. per acre) or a related iron source to enhance color, as needed. If manganese deficiency is suspected, apply manganese monthly at 0.25 lb/acre.

Table 2. Suggested yearly maintenance schedule for St. Augustinegrass.(from McCarty and Cisar, 1995b).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Florida*												
low maintenance	-	-	C[1]	-	-	Fe[2]	-	-	C	-	-	-
high maintenance	-	-	C	-	N[3]	Fe	N	-	C	-	-	-
South Florida												
low maintenance	-	C	-	-	N	Fe	-	-	-	C	-	-
high maintenance	-	C	-	-	N	Fe	N	-	-	C	-	N

* The arbitrary dividing line between north and south Florida is a straight east-west line from coast to coast through Orlando.

1. Apply a complete (C) fertilizer source (e.g., 16-4-8) at a rate of 1 lb. of nitrogen per 1000 sq ft (e.g., 6.2 lb 16-4-8 per 1000 sq ft).

2. Iron (Fe) may be supplied with ferrous sulfate (2 oz in 3-5 gal water per 1000 sq ft) or a chelated iron source.

3. Apply the equivalent of 1 lb of nitrogen (N) per 1000 sq ft as a slow release form (e.g., IBDU, SCU, urea formaldehyde, milorganite, etc.) to help prevent succulent growth which is more susceptible to chinch bug damage.

Table 3. Suggested fertilization schedule for bahiagrass lawns.(from McCarty and Cisar, 1997)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Florida[1]												
Low maintenance	-	-	C[2]	Fe[3]	-	-	-	-	C	Fe	-	-
High maintenance	-	-	C	Fe	N[4]	-	N	-	C	Fe	-	-
South Florida												
Low maintenance	-	C	Fe	-	-	-	-	C	-	N	-	-
High maintenance	-	C	Fe	-	N	-	-	-	C	N	-	N

1 The arbitrary dividing line between north and south Florida is a straight east-west line from coast to coast through Orlando.

2 Complete (C) fertilizer at 1.0 lb of nitrogen/1000 sq ft.

3 Apply iron to provide dark green color without stimulating excessive grass growth. Ferrous sulfate (2 oz in 3 to 5 gal water per 1000 sq ft) or a chelated iron source may be used.

4. Water soluble inorganic sources such as ammonium nitrate or ammonium sulfate applied at 1.0 lb of nitrogen/1000 sq ft.

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