Nutrient Evaluation for Sod Production within the Lake Okeechobee Watershed

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Abstract

Nutrient pollution from agricultural production is an environmental concern in the Everglades Agricultural Area. Sod farms within the Lake Okeechobee watershed in south Florida were surveyed to determine their production and fertilizer practices, and to determine the nitrogen (N) and phosphorous (P) impacts for the watershed. Ten of twenty sod farms participated in the in-person survey for a 50% response rate. Bahiagrass (*Paspalum notatum*) was grown on the greatest area at 5,463 ha (13,500 acres), followed-by St. Augustinegrass (*Stenotaphrum secundatum*) at 3,726 ha (9,208 acres), bermudagrass (*Cynodon dactylon* × *C. transvaalensis*. at 188 ha (465 acres), and zoysiagrass (*Zoysia japonica*) at 121 ha (299 acres). Growing and harvest cycle duration varied by turfgrass species. All farms follow guidelines for best management practices using fertilizer recommendations published by Florida's Department of Agriculture and Consumer Services. The predominate nitrogen (N) source used was ammonium sulfate, and diammonium phosphate was the most commonly utilized phosphorous (P) source. Survey results indicated that 90% of sod farms had net exports of N and 100% of sod farms had net export of P. Thus, sod production provides a route for removing these two nutrients from this fragile hydrologically-linked ecosystem.

Species used in this study: bahiagrass (*Paspalum notatum* Flüggé), bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy, St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze), zoysiagrass (*Zoysia japonica* Steud.).

Index words: bahiagrass, bermudagrass, nitrogen (N), phosphorous (P), St. Augustinegrass, turf, turfgrass, zoysiagrass.

Significance to the Horticulture Industry

Florida has the most land area in turfgrass sod production in the USA. Demand for sod continues as Florida's population has increased to be the third highest in the country in 2022. This study documents fertilizer inputs on sod farms in the Lake Okeechobee watershed, and specifically nitrogen (N) and phosphorous (P) exports via sod harvesting. Since the land occupied by those sod farms is within the Lake Okeechobee watershed basin, reducing N and P fertilizer inputs and increasing the removal of those nutrients through sod, could have an ultimate net positive effect of lessening the nutrient load into Lake Okeechobee and subsequent discharges into hydrologically-linked ecosystems such as the Everglades. In addition, the discharge of nutrient-rich water into coastal waters from Lake Okeechobee has been implicated in influencing Red Tide occurrence (i.e., harmful algal blooms). Thus, demonstrated reductions in fertilizer inputs and increased N and P exports away from fragile ecosystems could support the sod production industry's contribution to natural resource conservation and sustainable land management practices.

Introduction

Lake Okeechobee is the largest freshwater lake in Florida, and is the eighth largest freshwater lake in the U.S. Lake Okeechobee, also known as Florida's "inland sea", covers 1,900 square kilometers (730 square miles), but actually is a shallow lake with an average depth of 2.7 m (9 ft). The Lake Okeechobee Protection Act requires that proposed changes in land use will not result in increased phosphorous (P) loading over that of existing land uses (SFWMD, 2007).

In recent years, interest in converting farm or fallow land to commercial turfgrass sod production has increased in the Lake Okeechobee watershed, located in south Florida (personal communication, Turfgrass Producers of Florida; https://floridaturf.com/). Based on previous studies, sod farms in Florida are net exporters of P from the ecosystem (Graetz et al. 1991, 2002). Those studies determined that P is exported from the sod farm in both plant tissue and in soil contained within each harvested sod piece (Graetz et al. 1991, 2002). For example, a minimum of 25 kg P per ha (21 lb P per acre) was exported from bahiagrass (*Paspalum notatum* Flüggé) harvested from a sand/muck soil (Graetz et al. 1991, 2002). Two assumptions are in this value: (1) 70% of the sod field is harvested, with the remaining 30% left for propagation to reestablish the turfgrass stand, and (2) once established the production cycle is 10.5 months yielding 1.14 harvests per year (Graetz et al. 1991, 2002). Those reports further stated the information sampling and data compiling methods were limited, although currently these parameters are used by the South Florida Water Management District (West Palm Beach, FL) regulatory staff to evaluate the P load change related to land use change.

Furthermore, a total maximum daily load (TMDL) for nitrogen (N) in the tributaries of Lake Okeechobee has been developed (SFWMD, 2007) which has increased the level of interest of N concentration in land for the surrounding counties within the Lake Okeechobee watershed basin. However, no study has analyzed either P or N

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Table 1. List of questions for the 'Sod Nitrogen and Phosphorous Fertilizer Practice Survey'

Sod Nitrogen and Phosphorous Fertilizer Practice Survey[z]

The data collected is strictly confidential and the information you provide will remain anonymous. Please indicate N/A where the question is not applicable to you.

Production Practices

1. Sod farm name (optional), farm size, and location to be indicated by county.
2. Turfgrass species produced.
3. Land area per turfgrass species.
4. Soil type(s): muck*, sand, muck/sand mixture, and acreage of each. (*muck soil = organic soil, highly decomposed, mostly black in color)
5. Turfgrass species by soil type and land area.
6. Harvest cycle (months).
7. Harvest acreage per year per turfgrass species.
8. Portion of land area harvested (i.e., % of land area).
9. What is the thickness of the sod cut (inches)?
10. How do you propagate your sod (i.e., ribbons, or clear-cut and stolonization)?
11. Do you implement Best Management Practices (yes or no)?
    If yes, please indicate which ones:
    - soil testing for phosphorous
    - field rotations
    - sludge applications

Fertilizer Practices

12. Please list the type and quantity of purchased fertilizers.
13. What are the nitrogen and phosphorous contents of the applied fertilizers?
14. Do you apply nitrogen to your turfgrass sod fields (yes or no)?
15. If you apply nitrogen to your turfgrass sod fields, how much nitrogen do you apply annually and what source do you use?
16. What is the frequency and rate of nitrogen applications annually?
17. What month(s) is nitrogen fertilizer applications normally made?
18. Do you apply phosphorous to your turfgrass sod field (yes or no)?
19. If you apply phosphorous to your turfgrass sod fields, how much phosphorous do you apply annually and what source do you use?
20. What is the frequency and rate of phosphorous applications annually?
21. What months is phosphorous fertilizer applications normally made?
22. Do you fertilize pre- or post- sod harvest or both? If so, what rate of nitrogen and phosphorous or other fertilizers are applied and how far before or after harvest?
23. Have your fertilizer practices changed in the past five years? Ten years? Please describe.

Other Inputs

24. Do you apply other sources of nitrogen or phosphorous to your turfgrass sod fields?
    If so, list name of the source, quantity, and annual application rate.

Additional Comments

25. Any other comments?

[z]For those sod farms participating in the survey, the questions were completed during an in-person interview.

soil pools and processes within sod farms in that basin even though sod farming practices and sod farming land use areas have been adapted or changed (Cisar et al. 1992, Satterwaite et al. 2009). Therefore, the objective of this study was to reevaluate the P and N status of sod farms in the Lake Okeechobee watershed and to determine if those sod farms are net exporters of P and N from the ecosystem.

Materials and Methods

A sod farmer survey was conducted in the Lake Okeechobee watershed during January 2009. Survey questions (Table 1) were developed with input from members of the South Florida Water Management District (H. Zhao and R. Boney, West Palm Beach, FL), Florida Department of Agriculture and Consumer Services (Linda Crane; Tallahassee, FL) and the University of Florida's Ft. Lauderdale Research and Education Center (J. Cisar, M. McMillan, P. McGroary, and G. Snyder; Davie, FL). Twenty sod producers in the Lake Okeechobee watershed were selected at random, contacted, and asked to participate in the "Sod N and P Fertilizer Practice Survey". Sod farms that agreed to participate in the survey were visited in-person by J. Cisar, G. Snyder, and P. McGroary to expedite the collection of accurate data as well as to inform the sod producers of the context of the survey and the possible future use of the results. All respondents that participated in the survey chose to remain anonymous (i.e., no name attached to the completed survey form). Of note, without being offered anonymity, the sod producers would not have participated in the survey. The survey questions, while not covering all agronomic and economic aspects of sod production, attempted to assess practices utilized by the sod production industry in south Florida that are relevant to the objective of this study.

The N and P soil analyses were conducted at University of Florida's Belle Glade Research and Education Center (Belle Glade, FL). During February 2009, five sod samples of 90.3 cm^2 (14 in^2) $\times$ 2.54 cm (1 in) depth were randomly collected from each turfgrass species grown on each sod farm. All individual soil samples were oven-dried at 60 C (140 F) for four days, oven-dried weight recorded, then ground with a Wiley Mill (Model 110.3, Thomas Scientific; Swedesboro, NJ) to homogenize the sample for laboratory determination of total N and total P. Total N was calculated by adding total Kjedahl N plus nitrate plus nitrite together. Total P was measured by digesting the sample to measure for actual P. The methods used for determination of total N and total P

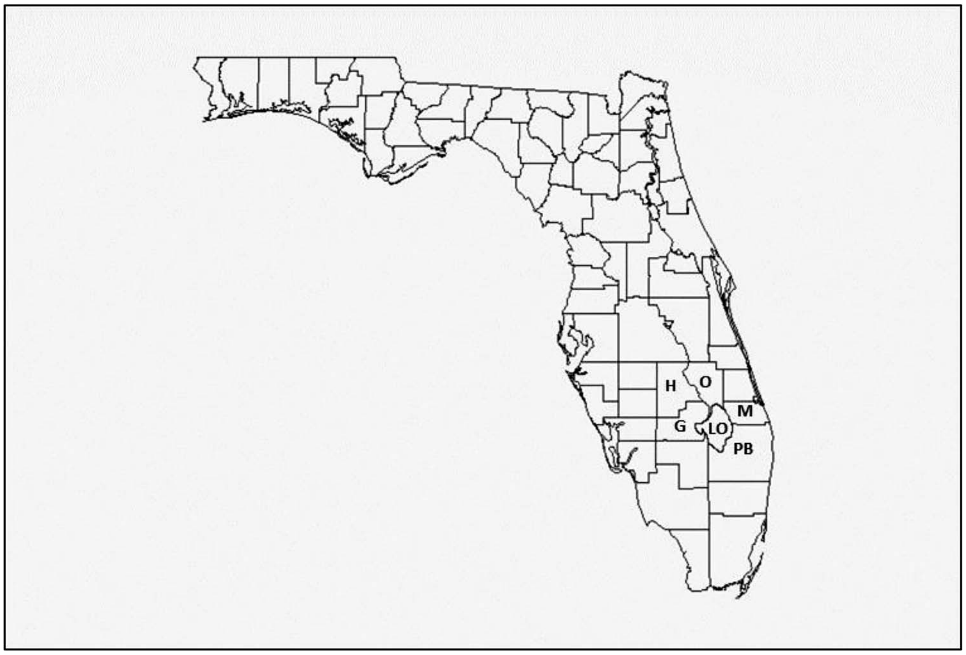

Fig. 1. **The ten sod farms that participated in the survey were located in Glades (G), Highlands (H), Martin (M), Okeechobee (O), and Palm Beach (PB) counties in south Florida, surrounding Lake Okeechobee (LO).**

were EPA 351.2, 353.2, and 365.4 (Sparks et al. 1996). All laboratory analysis results were recalculated to account for percent moisture for each soil sample. All N and P data means were calculated from five replications as a completely random experimental design (Mead et al. 2003).

Results and Discussion

Sod farms surveyed and location by county. Twenty sod producers were contacted within the Lake Okeechobee watershed, and ten agreed to participate in the survey for a 50% positive response rate. During January and February 2009, those sod farms were visited in-person to inform the sod producers about the purpose and context of the survey, and to expedite the collection of accurate data. All respondents chose to remain anonymous (i.e., no name attached to completed survey form), however, the sod farms that completed the survey were located in Glades, Highlands, Martin, Okeechobee, and Palm Beach counties (Fig. 1).

Turfgrass species produced and land area. A total land area of 9,499 ha (23,472 acres) was utilized for sod production among the ten farms that completed the survey (Fig. 2). Bahiagrass (*Paspalum notatum* Flüggé) was grown on the largest land area at 5,463 ha (13,500 acres), followed-by St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze) on 3,726 ha (9,208 acres), bermudagrass (*Cynodon dactylon* (L.) Pers. × Cynodon transvaalensis Burtt-Davy) on 188 ha (465 acres), and zoysiagrass (*Zoysia japonica* Steud. 'Empire') on 121 ha (299 acres) (Fig. 2). Of note, bahiagrass was grown on only two sod farms. Bahiagrass represented 58% of total land use for sod production, following by 39% for St. Augustinegrass, 2% for bermudagrass, and 1% for zoysiagrass (Fig. 2).

Soil type and land area. Among the ten sod farms surveyed representing 9,499 ha (23,472 acres) of sod land use, sod was produced on a total of 5,852 ha (14,461 acres) of sand, and 3,647 ha (9,011 acres) of muck soil (Fig. 3). Thus, 62% of all sod production occurred on sand, and 38% on muck soil (Fig. 3). The sand textural class was attributed to $\geq$ 85% sand particle size content, of which the majority was the fine sand-size fraction, and typically contained a range of 2 to 8% organic matter on those sod farms. Muck soil is defined as an organic soil (i.e., histosol), and the muck soil on those sod farms typically contained a range of 60 to 90% highly decomposed organic matter that is mostly black in color. Muck soils typically are found in Florida's Everglades Agricultural Area, and also in the low-lying fields surrounding Lake

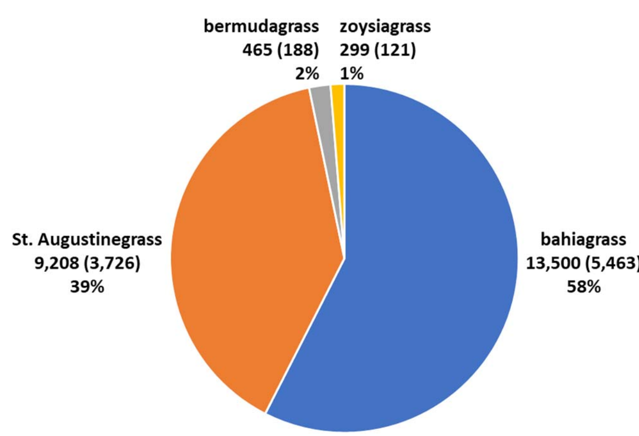

Fig. 2. **Land area devoted to sod production by turfgrass species in 2009 in the Lake Okeechobee watershed; listed by acres, (hectares), and percent of total. The total land area for all sod production was 23,472 acres (9,499 hectares). Data derived from survey information of ten sod farms within the Lake Okeechobee watershed.**

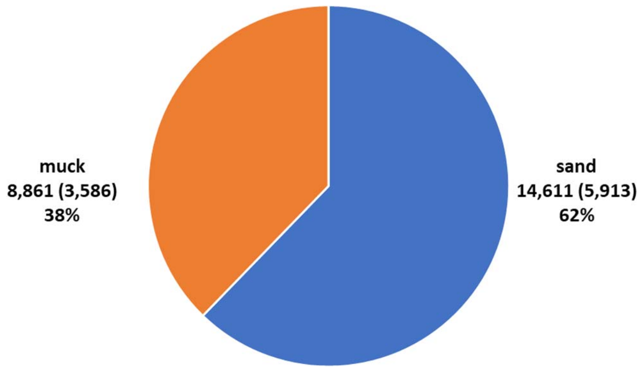

Fig. 3. Sand (≥ 85% sand particle size) or muck (i.e., histosols or organic soils which contain high organic matter content that is highly decomposed, and mostly black in color) soil in sod production by land area in Lake Okeechobee watershed in 2009; listed by acres, (hectares), and percent of total. The total land area for all sod production is 23,472 acres (9,499 hectares). Data derived from survey information of ten sod farms within the Lake Okeechobee watershed.

Placid and Lake Istokpoga in Central Florida (Williams 2008).

Turfgrass species by farm size, land area, and soil type. Sod farm size was defined as small (0-201 ha; 0-499 acres), medium (202-404 ha; 500-999 acres), large (405-809 ha; 1,000-1,999 acres), and very large (≥ 810 ha; ≥ 2,000 acres). Among the ten sod farms surveyed, 98% of sod production occurred on very large (73%) and large (25%) farms, and the remaining sod produced on small (2%) farms (Table 2). Among the total of 3,726 ha (9,208 acres) of St. Augustinegrass sod produced, 61% was on large farms, 39% very large farms, and < 1% small farms (Table 2). With bahiagrass, 100% of the 5,463 ha (13,500 acres) of sod was produced on very large farms (Table 2). Among the total of 188 ha (465 acres) of bermudagrass sod grown, 68% was on small farms and 32% on large farms (Table 2). With the 121 ha (299 acres) of zoysiagrass sod produced, 56% was on small farms, 26% on large farms, and 18% on very large farms (Table 2).

With St. Augustinegrass, 95% of sod was produced on muck (3,541 ha, 8,750 acres) and 5% produced on sand (185 ha, 458 acres) (Table 2). All bahiagrass sod (5,463 ha, 13,500 acres) was produced on sand (Table 2). With bermudagrass sod, 68% was produced on sand (127 ha, 315 acres) and 32% was produced on muck (61 ha, 150 acres) (Table 2). With zoysiagrass, 63% of sod was produced on sand (76 ha, 188 acres) and 37% on muck (45 ha, 111 acres) (Table 2). Of note, the determination of which turfgrass species is produced on sand or muck is dictated by the soil type that exists at each individual sod farm.

Harvest cycle and harvest acreage per year by turfgrass species. Harvest events per year (i.e., harvest = sod cut and removed) varied by turfgrass species (Table 3). Zoysiagrass and St. Augustinegrass typically is harvested once per year, bermudagrass twice per year, and bahiagrass once every four years (Table 3). Thus, only bermudagrass was capable of two harvests per year, resulting in a six-month production cycle. Zoysiagrass and St. Augustinegrass harvest time frequently depends upon sod market demand and agronomic production practices, but typically results in one harvest per year over a 12-month production cycle. Bahiagrass harvest cycle was much longer at three to four years, thus reflecting the dual use of bahiagrass as both a pasture and as a low resource input turfgrass.

Total harvested land area from highest to lowest was bahiagrass, St. Augustinegrass, bermudagrass, and zoysiagrass (Table 3). Actual percent of land area harvested, however, ranged from 86 to 87% each for zoysiagrass, St. Augustinegrass, and bermudagrass, and 65% for bahiagrass (Table 3). Actual land area harvested was highest for bahiagrass at 3,551 ha (8,775 acres), followed-by St. Augustinegrass at 3,205 ha (7,919 acres), bermudagrass at 164 ha (405 acres), and zoysiagrass at 104 ha (257 acres) (Table 3). Of note, sod producers attributed reduced land areas for bahiagrass harvest to more land needed for reestablishment and replanting, longer production cycles with less agronomic inputs, greater insect pest damage, invasive weed infestations, and submerged or wet areas that could not be harvested due to being grown on muck soils.

Thickness of sod cut. Harvested sod thickness was determined by measuring five random pieces of freshly cut sod per site (i.e., field or fields surveyed at each sod farm). The thickness of harvested or cut sod (i.e., soil or root zone depth removed with harvested sod) from all surveyed farms was approximately 2.54 cm (1.0 in), which is a commonly accepted practice with sod production for the purposes of minimizing the weight and optimizing the quality of sod during transport and delivery (Cockerham 2008). Of note, sod farmers in the Lake Okeechobee watershed often will determine or measure thickness-of-cut based on individual cored sod pieces. The actual sod-cutting blade typically measures 6.4 mm (0.25 in) in thickness. Also, with all turfgrass species produced for sod in the Lake Okeechobee watershed, the mowing height ranged from 3.8 to 10.1 cm (1.5 to 4 in) depending on market demand and customer expectations and was typically mowed at those heights-of-cut prior to harvest.

Sod propagation method. When a hectare (or acre) of warm-season turfgrass sod is harvested, only a portion of that land area is actually cut and removed from the field. Thus, vegetative "strips" or "ribbons" throughout each field are left unharvested to allow for regeneration of the next crop (Cockerham, 2008). For example, among the ten sod farms surveyed, 74% of total harvested land area (6,848 of 9,296 ha; 16,923 of 22,972 acres) for all turfgrass species was cut, removed, and exported from the farm site (Table 3). Recent improvements to maximize sod yield include satellite-guided steering technology that allows for more precise cuts with less waste and leaving narrower ribbons (i.e., narrow strips of turf remaining after harvest to establish into the next crop). Besides the need for vegetative turfgrass strips or ribbons to remain on the harvested field for reestablishment, limits to harvested acreage include excessively wet areas, weed infestations, loss of turfgrass stand density due to insect

Table 2. Total land area of sod grown in Lake Okeechobee watershed by turfgrass species, soil type, and farm size. Data derived from survey information of ten sod farms in 2009.

Farm size[z] and soil type[y]	Turfgrass species by land in production					Total (%)
	St. Augustinegrass	Bahiagrass	Bermudagrass	Zoysiagrass	*Total*	
	acres[x]					
Small						
Sand	8	0	315	168	491	
Muck	0	0	0	0	0	
Subtotal	8	0	315	168	491	2%
Medium						
Sand	0	0	0	0	0	
Muck	0	0	0	0	0	
Subtotal	0	0	0	0	0	0%
Large						
Sand	0	0	150	20	170	
Muck	5,650	0	0	56	5,706	
Subtotal	5,650	0	0	76	5,876	25%
Very Large						
Sand	450	13,500	0	0	13,950	
Muck	3,100	0	0	55	3,155	
Subtotal	3,550	13,500	0	55	17,105	73%
Summary:						
Sand	458	13,500	315	188	14,461	62%
Muck	8,750	0	150	111	9,011	38%
Total	9,208	13,500	465	299	23,472	
Total (%)	39%	58%	2%	1%	100%	100%

[z]Distribution of sod production land area by farm size was defined as: small = 0-499 acres (0-201 hectares); medium = 500-999 acres (202-404 hectares); large = 1,000-1,999 acres (405-809 hectares); and very large = $\geq$ 2,000 acres ($\geq$ 810 hectares).

[y]Soil: sand ($\geq$ 85% sand particle size) or muck (i.e., organic soil, highly decomposed, mostly black in color) soil.

[x]One acre = 0.405 hectare.

pests, land area occupied by ditches and roads, and uneven land surfaces and slopes.

Best management practices. All surveyed farms responded affirmatively that they adhere to best management practices and guidelines for sod production, referring to 'Water Quality/Quantity Best Management Practices for Florida Sod' (Bartnick et al. 2008) as their resource. From this survey, nine-out-of-ten or 90% of sod farms surveyed had net exports of N (Table 4). One farm producing bahiagrass on sand and zoysiagrass and St. Augustinegrass on muck soils applied more N than exported (Table 4). With P fertilizer, ten-out-of-ten or 100% of sod farms surveyed had net exports of P (Table 5). Within a few sod farms on muck soil, more P was probably applied than needed (Table 5).

Nitrogen. The N sources utilized varied by turfgrass species and sod farms, and included ammonium nitrate, ammonium sulfate, diammonium phosphate, monoammonium phosphate, sulfur coated urea, and sewage sludge (Table 4). The most commonly used N source was ammonium sulfate presumably due to low cost and its ability to alleviate high soil pH found in many Florida soils that have appreciable deposits of calcium carbonate (Table 4). For all turfgrass species produced on both sand and muck soil among all sod farms and total land area, the total N applied ranged from 21.8 to 176.2 kg·N ha^{-1} (48.00 to 388.50 lb·N $acre^{-1}$) (Table 4). The wide range of N applications reflect the difference between sand and muck (histosol) soils in Florida where it was demonstrated that N fertilizer applications did not negatively affect sod harvest cycles, sod quality, or sod strength on histosols in the Everglades Agricultural Area (Cisar et al. 1992).

Table 3. Number of sod harvest events per year and land area of harvested sod by turfgrass species for the Lake Okeechobee watershed. Data derived from survey information of ten sod farms in 2009.

Turfgrass	Number of harvest(s)·$year^{-1}$	Land area harvested·$cycle^{-1z}$	Actual land area Harvested[y]	Actual land area harvested·$cycle^{-1}$
	— number —	— acres[x] —	— % —	— acres[y] —
Zoysiagrass	1	299	86	257
Bermudagrass	2	465	87	405
St. Augustinegrass	1	9208	86	7,919
Bahiagrass	0.25	13,500	65	8,775
Total	-	23,472	-	17,356

[z]Harvest cycle refers to the time period for establishing, growing, then harvesting (i.e., cutting and removing) the sod.

[y]Repropagation methods for sod production after harvest varied by turfgrass species and among sod farms.

[x]One acre – 0.405 hectare.

Table 4. Nitrogen source and application rate by turfgrass species and soil, and soil nitrogen content, for sod in the Lake Okeechobee watershed. Data derived from survey information of ten sod farms in 2009.

Turf.[z]	Soil[y]	Farm no.[x]	N source[w]	Fertilizer analysis[v]	Total fertilizer applied per cycle[u]	Total land area cycle	Total N applied per cycle ("A")	Total soil weight of harvested sod[t]	Total N per lb of soil of harvested sod	Total N removed in soil of harvested sod ("B")	Net N exported with harvested sod ("B" – "A")
					$lb \cdot acre^{-1}$	acre	$lb \cdot acre^{-1}$	$lb \cdot acre^{-1}$	lb	$lb \cdot acre^{-1}$	$lb \cdot acre^{-1}$
Bahia.	sand	3	1, 3	20-5-10	800	10,000	160.00	202641.99	0.000075	15.19	(–144.81)
Bahia.	sand	8	2, 4	16-8-8	300	3,500	48.00	219598.06	0.001574	345.64	297.64
Berm.	sand	1	2	15-5-15	450	115	67.50	275238.13	0.000818	225.14	157.64
Berm.	sand	6	2	12-4-12	925	200	111.00	277020.25	0.002042	565.67	140.77
Berm.	sand	9	1, 2, 3	17-17-17	1,000	20	170.00	391929.07	0.000721	282.58	112.58
St Aug.	muck	3	1, 3	20-5-10	1,200	300	240.00	106073.14	0.001868	198.14	(–41.86)
St Aug.	muck	4	2, 3	9-9-16	1,350	1,400	121.50	79049.86	0.006249	493.98	368.32
St Aug.	muck	5	2	10-10-10	1,600	2,800	160.00	78823.18	0.003650	287.70	297.64
St Aug.	muck	7	1, 2, 3	12-4-15	1,800	1,300	216.00	111335.21	0.001389	154.64	(–61.36)
St Aug.	muck	9	2, 4, 6	17-17-17	1,400	150	238.00	87859.593	0.001592	139.87	(–10.13)
St. Aug.	muck	2	1, 3, 5	19-6-18	915	50	173.85	115629.74	0.001791	207.09	33.24
St Aug.	sand	10	2, 3	16-16-18	1,633	8	261.28	312448.13	0.000589	184.03	297.64
St. Aug.	sand	8	1, 2, 3	10-10-10	1,700	450	170.00	138738.24	0.002240	310.77	140.77
Zoysia.	muck	2	1, 3	12-3-12	915	50	109.80	116342.66	0.002659	309.35	199.55
Zoysia.	muck	3	1, 3, 5	20-0-10	1,200	55	240.00	282427.29	0.000357	100.82	(–139.18)
Zoysia.	muck	7	1, 2, 3	12-4-15	1,800	6	216.00	146081.85	0.004000	584.32	123.19
Zoysia.	sand	6	1, 2, 3	21-0-0	1,850	150	388.50	221668.93	0.001191	264.00	112.58
Zoysia.	sand	9	2	18-6-18	1,150	1,600	207.00	372265.98	0.000887	330.19	368.32
Zoysia.	sand	10	2, 3	16-16-18	1,633	18	388.50	275936.15	0.000382	105.403	140.77
									Total:	5104.52	2393.31

[z]Turfgrass species: Bahia. = bahiagrass; Berm. = bermudagrass; St. Aug. = St. Augustinegrass; Zoysia. = zoysiagrass. Repropagation methods for sod production after harvest from a growing season or harvest cycle varied by turfgrass species and among sod farms.

[y]Soil: sand ($\geq$ 85% sand particle size) or muck (i.e., organic soil, highly decomposed, mostly black in color) soil.

[x]Farms with the same number represent the same farm but different turfgrass species produced on that farm.

[w]Nitrogen (N) source: 1 = ammonium nitrate; 2 = ammonium sulfate; 3 = diammonium phosphate; 4 = monoammonium phosphate; 5 = SCU = sulfur coated urea; 6 = SLUDGE = sewage sludge.

[v]Fertilizer analysis as percent $N\text{-}P_2O_5\text{-}K_2O$.

[u]One lb (pound) = 0.454 kg; one acre = 0.405 hectare; harvest cycle refers to the time period for establishing, growing, then harvesting (i.e., cutting and removing) the sod.

[t]Soils data represents mean of five samples.

Table 5. Phosphorous source and application rate by turfgrass species and soil, and soil phosphorous content, for sod in the Lake Okeechobee Watershed. Data derived from survey information of ten sod farms in 2009.

Turf.[z]	Soil[y]	Farm no.[x]	P source[w]	Fertilizer analysis[v]	Total fertilizer applied per cycle[u]	Total land area cycle	Total P applied per cycle ("A")	Total soil weight of harvested sod	Total P per lb of soil of harvested sod	Total P removed in soil of harvested sod ("B")	Net P exported with harvested sod ("B" – "A")
					$lb \cdot acre^{-1}$	acre	$lb \cdot acre^{-1}$	$lb \cdot acre^{-1}$	lb	$lb \cdot acre^{-1}$	$lb \cdot acre^{-1}$
Bahia.	sand	3	3, 7	20-5-10	800	10,000	17.60	202641.99	0.000065	13.17	(–4.43)
Bahia.	sand	8	4	16-8-8	300	3,500	10.56	219598.06	0.000363	79.71	69.15
Berm.	sand	1	7	15-5-15	450	115	9.90	275238.13	0.000312	85.87	75.97
Berm.	sand	6	7	12-4-12	925	200	16.28	277020.25	0.000446	123.55	107.27
Berm.	sand	9	3, 7	17-17-17	1,000	20	74.80	391929.07	0.000323	126.59	51.79
St Aug.	muck	3	3, 7	20-5-10	1,200	300	26.40	106073.14	0.000409	43.38	16.98
St Aug.	muck	4	3, 7	9-9-16	1,350	1,400	53.46	79049.86	0.001125	88.93	35.47
St Aug.	muck	5	7	10-10-10	1,600	2,800	70.40	78823.18	0.001282	101.05	30.65
St Aug.	muck	7	3	12-4-15	1,800	1,300	31.68	111335.21	0.000174	19.37	(–12.31)
St Aug.	muck	9	4, 6	17-17-17	1,400	150	104.72	87859.593	0.000732	64.31	(–40.41)
St. Aug.	muck	2	3	19-6-18	915	50	24.15	115629.74	0.000443	51.22	27.07
St Aug.	sand	10	3	16-16-18	1,633	8	114.96	312448.13	0.000442	138.11	23.15
St. Aug.	sand	8	3, 7	10-10-10	1,700	450	74.80	138738.24	0.000116	16.09	(–58.71)
Zoysia.	muck	2	3, 7	12-3-12	915	50	12.07	116342.66	0.000282	32.80	20.73
Zoysia.	muck	3	3	20-0-10	1,200	55	0	282427.29	0.000125	35.30	35.30
Zoysia.	muck	7	3, 7	12-4-15	1,800	6	31.68	146081.85	0.000433	63.25	31.57
Zoysia.	sand	6	3	21-0-0	1,850	150	0	221668.93	0.000291	64.50	64.50
Zoysia.	sand	9	7	18-6-18	1,150	1,600	30.36	372265.98	0.000285	106.09	75.73
Zoysia.	sand	10	3	16-16-18	1,633	18	114.96	275936.15	0.000341	94.09	(–20.87)
									Total:	1347.38	528.60

[z]Turfgrass species: Bahia. = bahiagrass; Berm. = bermudagrass; St. Aug. = St. Augustinegrass; Zoysia. = zoysiagrass. Repropagation methods for sod production after harvest from a growing season or harvest cycle varied by turfgrass species and among sod farms.

[y]Soil: sand ($\geq$ 85% sand particle size) or muck (i.e., organic soil, highly decomposed, mostly black in color) soil.

[x]Farms with the same number represent the same farm but different turfgrass species produced on that farm.

[w]Phosphorous (P) source: 3 = diammonium phosphate; 4 = monoammonium phosphate; 6 = SLUDGE = sewage sludge; 7 = triple superphosphate.

[v]Fertilizer analysis as percent $N\text{-}P_2O_5\text{-}K_2O$.

[u]One lb (pound) = 0.454 kg; one acre = 0.405 hectare; harvest cycle refers to the time period for establishing, growing, then harvesting (i.e., cutting and removing) the sod.

[t]Soils data represents mean of five samples.

Conversely, sand root zones retain few nutrients and sod production requires frequent applications of fertilizer including N compared to sod production on muck soils.

Turfgrass cultivar and cropping system also were important factors for N application with zoysiagrass and St. Augustinegrass needing greater N inputs than bahiagrass (Table 4). In certain sod farms, bahiagrass is grown as a forage grass as well as for sod with little N applied if the primary use is as forage grass (Table 4). However, for sod-focused bahiagrass production on sand root zones, the N applications are far greater per sod production cycle (Table 4).

Laboratory analysis revealed total N contained in the soil harvested as sod ranged from 0.000034 to 0.002834 kg N per 0.454 kg harvested sod (0.000075 to 0.006249 lb N per lb of harvested sod) (Table 4). For all ten sod farms, the combined total amount of N removed in harvested sod was 2,315.37 kg·N ha^{-1} (5,104.52 lb·N $acre^{-1}$) (Table 4).

The net N exported with harvested sod (i.e., total N removed in the soil through harvested sod minus total N applied as fertilizer) ranged from (15.07 to 167.06 kg·N ha^{-1} (33.24 to 368.32 lb·N $acre^{-1}$) (Table 4). For all ten sod farms, the combined total amount of net N exported was 1,085.58 kg·N ha^{-1} (2,393.31 lb·N $acre^{-1}$) (Table 4). Although overall more N was exported from all 10 farms, there were three farms that exported less than applied, suggesting an opportunity for greater N management efficiency (Table 4).

Phosphorous. The P sources utilized also varied by turfgrass species and sod farms, and included diammonium phosphate, monoammonium phosphate, sewage sludge, and triple superphosphate (Table 5). The most used P source was diammonium phosphate (Table 5). For all turfgrass species produced on sand and muck soil among all sod farms, total P applied ranged from 0 to 52.14 kg·P ha^{-1} (0 to 114.96 lb·P $acre^{-1}$) (Table 5). Research on P fertilization for St. Augustinegrass sod production on histosols in south Florida indicated that P applications may not be necessary and should be applied only if soil test indices verify insufficient P levels (Cisar et al. 1992). Some farms did not apply P fertilizer, but the vast majority of sod producers did, thus suggesting opportunities to reduce P fertilizer inputs (Table 5).

Laboratory analysis revealed total P contained in the soil harvested as sod ranged from 0.000029 to 0.000581 kg P per 0.454 kg harvested sod (0.000065 to 0.001282 lb P per lb of harvested sod) (Table 5). For all ten sod farms, the combined total amount of P removed in harvested sod was 611.16 kg·P ha^{-1} (1,347.38 lb·P $acre^{-1}$) (Table 5).

The net P exported with harvested sod (i.e., total P removed in the soil through harvested sod minus total P applied as fertilizer) ranged from 7.70 to 48.65 kg·P ha^{-1} (16.98 to 107.27 lb·P $acre^{-1}$) (Table 5). For all ten sod farms, the combined total amount of net P exported was 239.76 kg·P ha^{-1} (528.60 lb·P $acre^{-1}$) (Table 5). Survey results indicated that five farms apply more P than exported (Table 5).

Of note, N and P content within leaf, stolon, and rhizome tissues of all four turfgrass species were not analyzed from the harvested sod collected during this survey. The N and P concentration of oven-dried plant tissues for the four turfgrass species would range from 1 to 2% N and 0.1 to 0.2% P (Cisar et al. 1992). Therefore, N and P content in plant tissues was considered to be negligible and therefore not included in this survey.

In conclusion, sod production is a major agricultural enterprise in the Lake Okeechobee watershed. The net positive export of N and P recorded from the ten surveyed sod farms in the region suggest that sod production provides a route for removing these two nutrients of impairment from this fragile hydrologically-linked ecosystem. Nevertheless, the observations from some participants having more N and P input than export illustrate the opportunities for extension education to improve N and P fertilization practices and export efficiency for sod producers in Florida. Highlighting scientifically-based research that provides guidelines for lowering fertilizer inputs, basing fertilizer application timings and rates on soil and/or turfgrass tissue testing benchmarks, and using slow-release nutrient sources may reduce the potential for adverse environmental impacts as well as being cost-effective strategies for sod producers in Florida.

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