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Modeling Evaluation of Alternative Management Practices and Reclaimed Water for Turfgrass Systems

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ABSTRACT

The use of reclaimed water for turfgrass irrigation is being implemented to conserve potable water supplies. Reclaimed water coupled with alternative management strategies may reduce offsite loadings of fertilizers and pesticides. The Environmental Policy Integrated Climate (EPIC) water quality model was used to evaluate alternative management practices and reclaimed water for a southern turfgrass system. One green and fairway were modeled for a 65-yr period of climatic record with four treatments. Specifically, the treatments were normal water normal management (NWNM), normal water reduced management (NWRM), reclaimed water normal management (RWNM), and reclaimed water reduced management (RWRM). Surface and subsurface nitrate (NO_3–N), fenamiphos (ethyl 3-methyl-4-(methylthio)phenyl (1-methylethyl)phosphoramidate), and MSMA (monosodium methanearsonate) losses were evaluated. Significant differences were predicted in NO_3–N runoff and leachate losses from green management. Mean annual NO_3–N losses from runoff were 2.85 kg ha^{-1} (NWNM) and 2.05 kg ha^{-1} (RWRM). Significant reductions in mean annual surface and subsurface NO_3–N losses from fairway conditions were simulated when comparing NWNM (5.11 kg ha^{-1} surface; 1.68 kg ha^{-1} subsurface) to RWRM (2.69 kg ha^{-1} surface; 0.90 kg ha^{-1} subsurface). The cited differences in NO_3–N losses in runoff and leachate from green and fairway conditions were attributed primarily to irrigation strategies and excess rainfall. Predicted average annual pesticide recovery in runoff and leachate was <0.01% of applied and no significant differences were predicted with respect to treatments. This modeling strategy provides valuable insight into the relative efficacy of implementing reduced management practices for turfgrass systems.

WATER CONSERVATION is a major topic in the turfgrass industry due to (i) an increase in competition for water supply, (ii) availability during drought times, (iii) expense, and (iv) advanced education of turfgrass managers (Carrow, 1994). As consumer demand for potable water continues to mount, alternative practices for traditional management will be incorporated into daily routines of golf course maintenance. Using reclaimed water for irrigation is a significant means being implemented to conserve potable water supplies. Reclaimed water in this case refers to tertiary-treated wastewater that could be re-introduced to the stream. Optimal use of reclaimed water coupled with reduced chemical applications could potentially retard offsite loadings to water supplies by considerable amounts.

Mancino and Pepper (1994) discuss the benefits of using reclaimed water for turfgrass irrigation. They conclude that using reclaimed water permits reduced commercial fertilizer application due to residual N present in reclaimed water. Using reclaimed water also avoids surface water or ocean dumping.

Evaluation of the offsite impacts of using reclaimed water for irrigation in combination with pesticide applications has not been fully studied. Two commonly used turfgrass pesticides are fenamiphos (ethyl 3-methyl-4-(methylthio)phenyl (1-methylethyl)phosphoramidate), and monosodium methanearsonate (MSMA). Monosodium methanearsonate is an EPA Toxicity Category III post-emergent herbicide (Ahrens, 1994, p. 209–211). Monosodium methanearsonate is considered a moderately toxic compound with low environmental mobility (Balogh and Anderson, 1992). Monosodium methanearsonate is considered slightly to moderately toxic to fish such as bluegill sunfish (*Lempomis macrochirus*) (Ahrens, 1994, p. 209–211). The average 4-d LC_{50} for juvenile bluegill sunfish is 25.2 mg L^{-1} (Murphy, 1992). Fenamiphos is considered a highly toxic compound and is classified as a restricted use pesticide. As a relatively mobile and moderately persistent compound used for nematode control on greens, there are concerns regarding offsite transport and exposure to fenamiphos (Balogh and Anderson, 1992). The lifetime health advisory level (HAL) for fenamiphos is 2 μg L^{-1} (Kamrin, 1997).

To meet the demand for environmental friendly golf courses, turf scientists will be challenged to conserve water and alter management strategies while providing uniform, pest-free turfgrass. One means of studying potential impacts of alternative management systems is computer modeling. The Erosion Productivity Impact Calculator (Williams et al., 1984) and more recently Environmental Policy Integrated Climate (EPIC)

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Abbreviations: EPIC, Environmental Policy Integrated Climate; NWNM, normal water normal management; NWRM, normal water reduced management; RWNM, reclaimed water normal management; RWRM, reclaimed water reduced management; SCU, sulfur-coated urea; AS, ammonium sulfate; AWC, available water capacity; HAL, health advisory level; LC_{50}, 50% lethal concentration.

model (Williams et al., 1996) is a comprehensive field-scale model that operates on a daily time step. EPIC was developed to predict the effects of management decisions on soil and water resources and crop production for agricultural field-scale areas. The major strength of EPIC is the ability to simulate agricultural management practices with a comprehensive crop growth component. A component by component detailed discussion is documented in Williams (1995). EPIC has previously been used to simulate golf course management (Mandel, 1997; King and Balogh, 1997; Rosenthal and Hipp, 1993).

King and Balogh (1997) reported that simulated turfgrass water use in a growing season averaged 5.2 and 5.9 mm d^{-1} for green and fairway conditions, respectively. Maximum EPIC simulated water use was 12.2 mm d^{-1} for the green and 12.4 mm d^{-1} for the fairway. EPIC simulations were in the range (2.5–7.5 mm d^{-1} with a maximum as high as 12 mm d^{-1}) of values reported by Beard (1985). Simulated runoff correlated well with similar runoff data reported by Gross et al. (1990). They also reported EPIC-predicted fertilizer losses in the leachate and runoff to be consistent with data presented by Yates (1995) and Birdwell (1995).

The objective of this work was to evaluate the use of reclaimed water and alternative management on offsite loadings of NO_3–N, fenamiphos, and MSMA from a green and fairway condition. Because of construction procedures and soil differences both conditions were simulated. The use of a computer simulation model (EPIC) demonstrates a strategy to evaluate the relative efficacy of alternative practices prior to field implementation.

METHODS AND PROCEDURES

Experimental Data

Climatic and site specific data (Table 1) used for model input were collected for one green and fairway condition from an intensively managed golf course in the semiarid climatic region of Austin, TX. Mean annual rainfall for the 65-yr period of record was 835.3 mm (Fig. 1). The fairway soil was an Austin silty clay (fine-silty, carbonatic, thermic Udorthentic Haplustoll). The green was constructed to USGA specifications (USGA, 1993). Both fairway and green sites were seeded with bermudagrass (*Cynodon dactylon* L. Pers.). Greens were overseeded with perennial ryegrass (*Lolium perenne* L.) from November through March to provide year-round living turf. The rate of overseeding is not critical in the realm of modeling.

Table 1. Summary of baseline parameter values for EPIC turfgrass simulations in Austin, TX.

Parameter	Fairway site	Green site
Precipitation and temperature	**1931–1995 daily records**	
Area, ha	**1.05**	**0.08**
SCS curve no.	**68**	**55**
Mannings "n" (surface)	**0.24**	**0.15**
Slope length, m	**18.0**	**19.5**
Slope steepness, m m⁻¹	**0.05**	**0.015**
Profile depth, m	**0.76**	**0.56‡**
Sand content, %	**10**	**95**
Silt content, %	**45**	**4**
Saturated conductivity,† mm h⁻¹	**8.89**	**152**

† Conductivity of layer just below the thatch layer.
‡ The putting green profile includes the rootzone mix, choker layer, and gravel drainage bed.

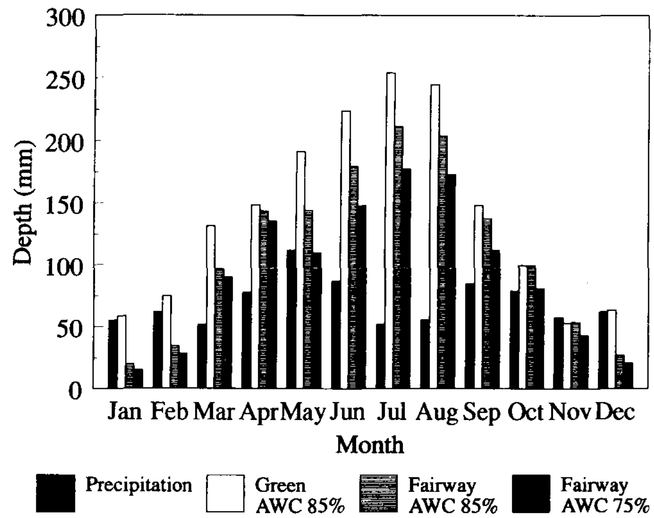

Fig. 1. Average precipitation and irrigation depths by month for 65-yr simulation.

When modeling crop growth a maximum leaf area index is specified and then tried to achieve. Fairways were not overseeded. The growth is dependent upon nutrient, water, and climate stress, and clippings (Williams, 1995). Simulated management practices consisted of mowing, fertilizing, irrigation, and pesticide applications.

Fertilizer applications included both sulfur-coated urea (SCU as 25–3–9) and ammonium sulfate (AS as 15–5–10). Sulfur-coated urea was input as 100% ammonia when released while AS was applied as mineral N. To account for the slow release mechanism of SCU a release schedule was developed from the work reviewed by Turner and Hummel (1992). An initial 30% release was followed by 14% releases at 7-d intervals until the amount of fertilizer was exhausted. This was accomplished manually since EPIC cannot simulate split fertilizer applications. Fertilizer rates are typically elevated for high traffic public golf courses in the Austin, TX, area (Balogh et al., 1995). Irrigation was triggered based on available water capacity (AWC). Typical irrigation was performed based on 85% AWC. The 85% AWC was equivalent to 9.8 mm deficit for the green and 12.9 mm deficit for the fairway. The proposed 75% AWC irrigation strategy for fairways is equivalent to a 21.5 mm deficit. When the AWC dropped below these levels, the model would irrigate to bring the AWC equivalent to field capacity. The growing season for bermudagrass is typically from 15 April to 5 November. Pesticide applications were performed based on typical management practices for this region. Prediction of one commonly used pesticide for each condition was analyzed. Fenamiphos was simulated for the green while MSMA was simulated for the fairway (Table 2). Mowing operations were performed three times per week for the fairway and daily for the green. Simulated clippings were removed on the greens and left on the fairways.

The notation used is normal water normal management (NWNM), normal water reduced management (NWRM), reclaimed water normal management (RWNM), and reclaimed water reduced management (RWRM). Typical and alternative

Table 2. Summary of chemical properties used in simulations.†

Chemical	Water solubility	Soil half-life	Foliage half-life	Washoff fraction	Adsorption coefficient K_{oc}
	mg L⁻¹	d	d		
Fenamiphos	**400**	**19**	**0.1**	**0.05**	**100**
MSMA	**1 400 000**	**10**	**10**	**0.95**	**100 000**

† Source: chemical database in EPIC (Williams, 1995).

Table 3. Summary of typical and alternative fairway management strategies† near Austin, TX.

Activity	NWNM	NWRM	RWNM	RWRM
Irrigation				
Growing season	@85% AWC‡	@75% AWC	@85% AWC	@75% AWC
Dormant season	@85% AWC	@75% AWC	@85% AWC	@75% AWC
Fert. apps., kg ha^{-1}				
15 Mar.	244 SCU§	244 SCU	244 SCU	244 SCU
10 Apr.	–	–	326 AS	–
8 May	326 AS¶	277 AS	–	–
1 June	–	–	147 SCU; 163 AS	195 SCU
20 June	326 AS	277 AS	–	–
1 Aug.	244 SCU	195 SCU	244 SCU	–
10 Sept.	–	–	147 SCU	147 SCU
12 Sept.	244 SCU	244 SCU	–	–
1 Nov.	326 AS	195 AS	–	–
Pest. apps., kg ha^{-1}				
MSMA#				
1 June	4.49 liquid#	3.37 liquid	4.49 liquid	3.37 liquid
1 Aug.	0.63 liquid	0.45 liquid	0.63 liquid	0.45 liquid

† Strategies represent current practices aimed at target dates.
‡ AWC is available water capacity based on 85.9 mm total water in the profile.
§ SCU is sulfur-coated urea as (25–3–9): 25% nitrogen, 3% phosphorus, 9 potassium.
¶ AS is ammonium sulfate as (15–5–10): 15% nitrogen, 5% phosphorus, 10% potassium.
# kg of active ingredient.

fairway management practices are summarized in Table 3 while green management practices are summarized in Table 4. The tertiary treated reclaimed water potentially available for this specific application was analyzed at 6.3 mg L^{-1} NO_3–N.

RESULTS AND DISCUSSION

Greens

Neither reclaimed water nor management affected the water balance associated with the green simulation (Table 5). Mean annual runoff was simulated at 47 mm yr^{-1}, while percolate was predicted at 453 mm yr^{-1}. Approximately 1700 mm yr^{-1} of irrigation was applied while 1900 mm yr^{-1} evapotranspiration (ET) was estimated. ET was roughly 75% of irrigation and precipitation.

Type of irrigation water had no significant effect on surface losses of NO_3–N from the green (Table 7). This should be expected since there was little or no reduction in actual N applied with respect to irrigation water type. Decreasing N application amounts did significantly reduce loadings in the surface runoff. When evaluating leachate from the greens, irrigation water, as well as management significantly influenced NO_3–N transport (Table 7). The amount of applied N through irrigation was more than enough to account for the reduction in applied commercial N. In this simulation, lower application rates and normal irrigation water (NWRM) provided lower loading rates to subsurface waters compared to all other treatments. Thus, improper management of reclaimed irrigation water could provide more potential for offsite fertilizer transport. However, this can be overcome by further reducing the amount of actual applied commercial fertilizer.

Table 4. Summary of typical and alternative green management strategies† near Austin, TX.

Activity	NWNM	NWRM	RWNM	RWRM
Fert. apps. (kg ha^{-1})				
1 Jan.	293 SCU‡; 163 AS§	163 AS	293 SCU; 163 AS	163 AS
1 Feb.	293 SCU; 163 AS	163 AS	293 SCU; 163 AS	163 AS
1 Mar.	293 SCU; 163 AS	98 SCU; 163 AS	293 SCU; 163 AS	98 SCU
15 Mar.	–	163 AS	–	163 AS
1 Apr.	293 SCU	98 SCU	292.2 SCU	98 SCU
15 Apr.	163 AS	163 AS	163 AS	163 AS
1 May	147 SCU; 81 AS	147 SCU; 81 AS	147 SCU; 81 AS	147 SCU; 81 AS
15 May	147 SCU; 81 AS	147 SCU; 81 AS	147 SCU; 81 AS	147 SCU; 81 AS
1 June	147 SCU; 81 AS	147 SCU; 163 AS	147 SCU; 81 AS	147 SCU; 81 AS
15 June	147 SCU; 81 AS	147 SCU; 163 AS	147 SCU; 81 AS	147 SCU; 81 AS
1 July	147 SCU; 81 AS	98 SCU; 81 AS	147 SCU; 81 AS	98 SCU; 81 AS
15 July	147 SCU; 81 AS	98 SCU; 81 AS	147 SCU; 81 AS	98 SCU; 81 AS
1 Aug.	147 SCU; 81 AS	98 SCU; 81 AS	147 SCU; 81 AS	98 SCU; 81 AS
15 Aug.	147 SCU; 81 AS	98 SCU; 81 AS	147 SCU; 81 AS	98 SCU; 81 AS
1 Sept	147 SCU; 81 AS	98 SCU; 81 AS	147 SCU; 81 AS	98 SCU; 81 AS
15 Sept.	147 SCU; 81 AS	147 SCU; 81 AS	147 SCU; 81 AS	98 SCU; 81 AS
1 Oct.	293 SCU; 163 AS	195 SCU	293 SCU; 163 AS	98 SCU
15 Oct.	–	163 AS	–	163 AS
1 Nov.	293 SCU; 163 AS	163 AS	293 SCU; 163 AS	163 AS
15 Nov.	–	163 AS	–	163 AS
1 Dec.	293 SCU; 163 AS	163 AS	293 SCU; 163 AS	163 AS
Pest. apps., kg ha^{-1}				
Fenamiphos¶				
30 July	11.2 granular	11.2 granular#	11.2 granular	11.2 granular#

† Strategies represent current practices aimed at target dates; irrigation was performed at 85% available water capacity (AWC) based on 65.5 mm total water capacity in the profile.
‡ SCU is sulfur-coated urea as (25–3–9); 25% nitrogen, 3% phosphorus, 9% potassium.
§ AS is ammonium sulfate as (15–5–10); 15% nitrogen, 5% phosphorus, 10% potassium.
¶ kg of active ingredient.
# Applied once every 4 years.

Table 5. Average annual summary of simulated hydrology, NO_3–N losses, and fenamiphos losses for green conditions under all management strategies.

Simulated output	NWNM†	NWRM	RWNM	RWRM
Water balance				
Irrigation, mm	1693	1694	1697	1695
ET, mm	1890	1891	1894	1892
Runoff, mm	47	47	47	47
Percolation, mm	453	453	454	454
Precipitation, mm	835	835	835	835
NO_3–N events				
NO_3–N runoff events per year	9.3	9.4	9.4	9.3
NO_3–N runoff events >10 mg L^{-1}	2.4	2.0	2.7	2.2
NO_3–N percolate events per year	32.0	32.4	35.2	33.2
NO_3–N percolate events >10 mg L^{-1}	14.7	13.2	18.9	14.8
Percent mass recovered in runoff	0.2	0.3	0.2	0.3
Percent mass recovered in percolate	7.5	8.1	10.1	10.9
Pesticide loss events				
Fenamiphos runoff events per year	1.58	0.89	1.65	0.89
Fenamiphos runoff events >2 μg L^{-1}	0.23	0.09	0.25	0.08
Fenamiphos percolate events per year	4.49	2.95	4.78	2.86
Fenamiphos percolate events >2 μg L^{-1}	0.02	0.02	0	0
Mass recovered in runoff, g ha^{-1}	0.16	0.24	0.15	0.19
Mass recovered in percolate, g ha^{-1}	0.09	0.08	0.09	0.06

† Notation is NWNM = normal water normal management; NWRM = normal water reduced management; RWNM = reclaimed water normal management; RWRM = reclaimed water reduced management.

The array of simulated green managements resulted in approximately 9.3 NO_3–N containing runoff events and 33.2 percolate events per year (Table 5). Roughly 25% of the runoff events and 46% of the percolate events exceeded the drinking water standard 10 mg L^{-1}. Approximately 0.25% of the applied N was recovered as NO_3–N in the runoff and 9.1% was recovered in the percolate. The largest NO_3–N mass losses in the runoff were predicted in October, November, and December (Fig. 2). This suggests possible overirrigation (Fig. 1) and fertilization during those months. A similar evaluation of leachate predictions shows a rapid increase in NO_3–N loss in the winter months of November, December, and January as well as in March and April (Fig. 3). These times correspond to early growing season periods. Winter application of fertilizers is generally practiced because of overseeding. When courses are overseeded, the nutrients are assumed to be consumed rapidly. However, modeling results suggests that less N could be applied before the growing periods. Although somewhat elevated, relatively large NO_3–N losses do correspond with limited measured data for similar management conditions (Walker and Branham, 1992; Exner et al., 1991). The high simulated NO_3–N losses could also be due to an inadequacy of the model to accurately account for the suspension of fertilizers in the thatch and subsequent release during the early growing periods.

Surface and subsurface losses of fenamiphos applied to the green were not significantly influenced by management or irrigation type (Table 8). In fact, the model predictions indicate increases in subsurface fenamiphos losses when using a reduction in application. This was not expected. However, an examination of plant development can help explain this result. The shift in time and amount of N application resulted in plant N stress. The result of N stress was less leaf area for the fenamiphos to be lodged upon. This reduction in leaf area resulted in more fenamiphos being applied to the soil, which would be immediately available for transport via surface or subsurface pathways. Thus, an increase in

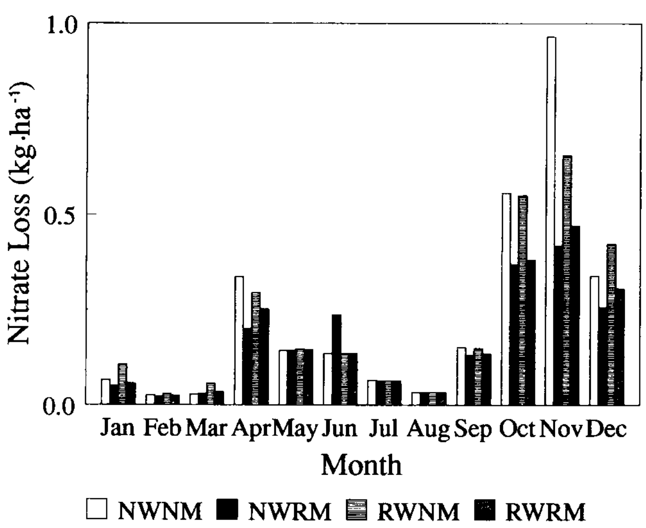

Fig. 2. Simulated average monthly NO_3–N loss recovered in the surface runoff from a green condition for all management strategies.

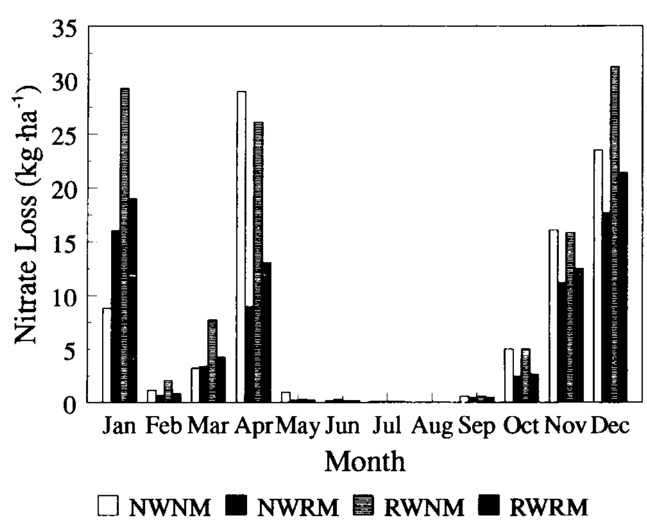

Fig. 3. Simulated average monthly NO_3–N loss recovered in the leachate from a green condition for all management strategies.

Table 6. Average annual summary of simulated hydrology, NO_3–N losses, and MSMA losses for fairway conditions under all management strategies.

Simulated output	NWNM†	NWRM	RWNM	RWRM
Water balance				
Irrigation, mm	1351	1135	1349	1111
ET, mm	1655	1508	1653	1483
Runoff, mm	150	142	150	142
Percolation, mm	352	294	351	295
Precipitation, mm	835	835	835	835
NO_3–N events				
NO_3–N runoff events per year	21.5	20.7	21.5	20.7
NO_3–N runoff events >10 mg L^{-1}	3.3	3.2	3.0	2.1
NO_3–N percolate events per year	39.8	34.0	38.3	31.3
NO_3–N percolate events >10 mg L^{-1}	0.7	0.5	0.7	0.1
Percent mass recovered in runoff	1.6	1.4	1.8	1.8
Percent mass recovered in percolate	0.5	0.4	0.7	0.6
Pesticide loss events				
MSMA runoff events per year	5.02	4.58	5.09	4.72
MSMA runoff events >25.2 mg L^{-1}	0	0	0	0
MSMA percolate events per year	0	0	0	0
MSMA percolate events >25.2 mg L^{-1}	0	0	0	0
Mass recovered in runoff (g ha^{-1})	T‡	T	T	T
Mass recovered in percolate (g ha^{-1})	0	0	0	0

† Notation is NWNM = normal water normal management; NWRM = normal water reduced management; RWNM = reclaimed water normal management; RWRM = reclaimed water reduced management.
‡ T represents a trace (<0.01 g ha^{-1}).

fenamiphos losses when reduced management is practiced. This may be avoided by shifting the application of fertilizers closer to the time when fenamiphos is to be applied. This would reduce the N stress and provide more leaf area for the application of fenamiphos.

Surface losses of fenamiphos were predicted to occur one to two times per year while subsurface losses were predicted to occur between two and five times per year (Table 5). On average a fenamiphos runoff event exceeding 2 μg L^{-1} (HAL) (Kamrin, 1997) occurred once every 4 to 6 yr while in the leachate less than one event every 50 yr was predicted. Less than 0.01% of the applied fenamiphos was recovered in the runoff and leachate. Based on the EPIC simulation, exposure to fenamiphos is generally well below those concentrations anticipated to have any adverse effect on human health.

Fairways

Reducing the irrigation trigger amount from 85% AWC to 75% AWC resulted in approximately 200 mm yr^{-1} less water use (Table 6). Predicted mean annual runoff decreased 8 mm yr^{-1} while percolation decreased roughly 50 mm yr^{-1} when irrigation trigger amount was reduced. Total simulated ET was approximately 75% of the combined precipitation and irrigation. The reduction in consumptive use of irrigation water represents a considerable water conservation strategy. Research has demonstrated that high quality turfgrass can be maintained at these irrigation levels (Balogh and Watson, 1992; Kneebone et al., 1992).

Surface and subsurface NO_3–N losses from fairways were significantly lower when comparing NWNM to RWRM (Table 7). Annual surface losses of NO_3–N were reduced 47% when comparing NWNM to RWRM while leachate loss was reduced by 46% using the same comparison. These reductions were a function of management as well as lower volumes of irrigation (Table 6). With respect to NO_3–N losses from a fairway, a combination of reduced management and reclaimed water (RWRM) clearly provides for less overall offsite transport when compared to other modeled treatments.

The various management scenarios modeled for fairway conditions averaged 21 NO_3–N containing runoff events per year (Table 6). Of those, roughly 14% exceeded the 10 mg L^{-1} drinking water standard. In the percolate, approximately 35.9 events occurred per year with 1.3% exceeding the drinking water standard. Approximately 1.7% of applied N was predicted to be recovered in the runoff while 0.6% was predicted to be recovered in the percolate. The largest part of the runoff NO_3–N was recovered in April and May and October, November, and December (Fig. 4). The largest portion of mass recovered in the percolate was in January and April (Fig. 5). These times correspond with the greening

Table 7. Applied N and predicted average annual losses of NO_3–N in the surface runoff and percolate for a green and fairway condition by management for 65-yr period of simulation.

Treatment	Applied commercial N		NO_3–N in the surface runoff		NO_3–N in the leachate	
	Green	Fairway	Green	Fairway	Green	Fairway
	kg ha^{-1}					
NWNM†	1174	330	2.85 a‡	5.11 a	88.7 c	1.68 a
NWRM	758	303	1.96 b	4.26 b	61.6 b	1.29 abc
RWNM	1174	208	2.65 a	3.75 b	118.4 a	1.46 b
RWRM	685	147	2.05 b	2.69 c	74.8 c	0.90 c

† Notation is NWNM = normal water normal management; NWRM = normal water reduced management; RWNM = reclaimed water normal management; RWRM = reclaimed water reduced management.
‡ Values in columns followed by the same letter are not significantly different (Student's paired *t*-test $P < 0.01$).

Table 8. Predicted average annual losses of MSMA and fenamiphos for the surface runoff and percolate by management for 65-yr period of simulation.

	Green losses of fenamiphos		Fairway losses of MSMA	
Treatment	Runoff	Leachate	Runoff	Leachate
	g ha^{-1}			
NWNM†	0.15 a‡	0.09 a	T§	–
NWRM	0.24 a	0.08 a	T	–
RWNM	0.15 a	0.09 a	T	–
RWRM	0.19 a	0.06 a	T	–

† Notation is NWNM = normal water normal management; NWRM = normal water reduced management; RWNM = reclaimed water normal management; RWRM = reclaimed water reduced management.
‡ Values in columns followed by the same letter are not significantly different (Student's paired t-test $P < 0.01$).
§ T represents a trace (<0.01 g ha^{-1}).

(spring) and dormancy (winter) periods for bermudagrass growth. Fairways are not overseeded. As with fertilizer application on the green, this would suggest possible overfertilization at these times. As previously discussed with respect to greens, model limitation in turfgrass environments could play a role in distorting the estimate of NO_3–N losses.

Surface losses of MSMA from a fairway were predicted to occur approximately five times per year regardless of treatment (Table 6). No events were predicted in which 25.2 mg L^{-1} (toxicity level for fish) would be exceeded. On average, <0.01% of the applied MSMA was predicted to be recovered with the remaining MSMA being degraded. No subsurface losses of MSMA were predicted. Based on the EPIC simulation, exposure to MSMA in leachate or runoff is well below fish acute and chronic toxicity exposure levels.

CONCLUSIONS

The use of reclaimed water coupled with a reduction in applied fertilizers and irrigation amounts (RWRM) resulted in significant decreases of offsite NO_3–N transport when compared to other treatments on fairway conditions. The use of normal water and reduced management (NWRM) produced the least amount of offsite NO_3–N transport from a green. The model simulations indicated N levels could be further reduced when using reclaimed water. Pesticide losses were not significantly reduced by use of reclaimed water or management. The levels of pesticides recovered in the leachate and runoff represented a minute fraction of the applied amounts. Also, the use of reclaimed water and a 10% reduction in the irrigation trigger could significantly reduce demands on potable water supplies.

Continued efforts should focus on optimal levels of irrigation and fertilizer application needed to sustain plush turfgrass conditions while preserving the surrounding environment. An optimization routine could be built around a model such as this to find the levels and times at which fertilizer applications should be made in conjunction with reclaimed water.

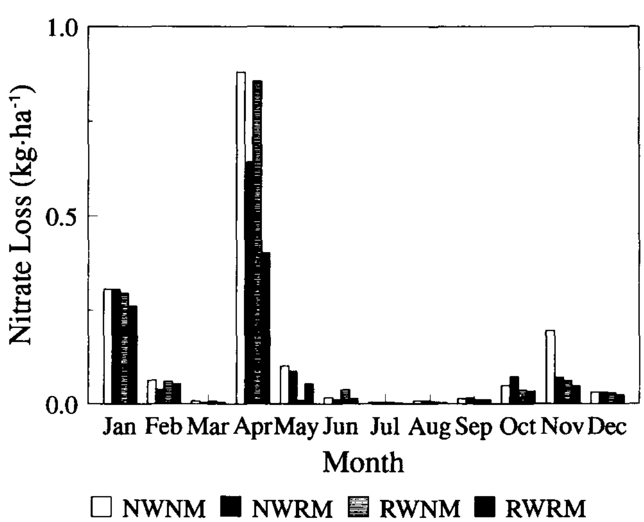

Fig. 4. Simulated average monthly NO_3–N loss recovered in the surface runoff from a fairway condition for all management strategies.

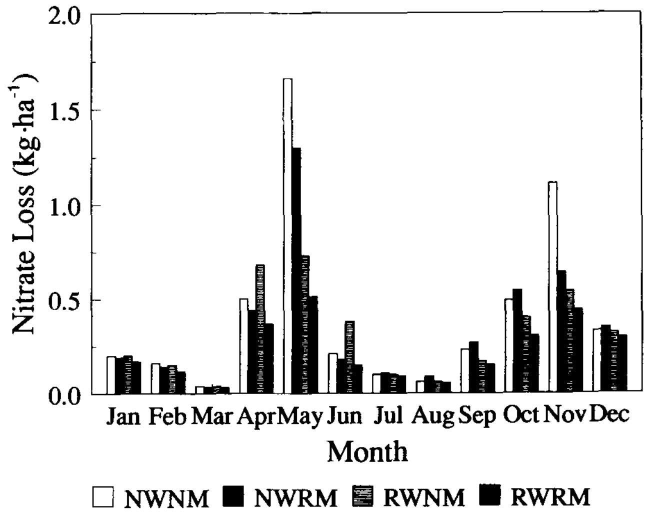

Fig. 5. Simulated average monthly NO_3–N loss recovered in the leachate from a fairway condition for all management strategies.

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