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Response of tropical turfgrasses to recycled water in southern Queensland

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Abstract. The effects of recycled water (effluent) on 8 tropical grasses growing in 100-L bags of sand were studied in Murrumba Downs, just north of Brisbane in southern Queensland (27.4°S, 153.1°E). The species used were: *Axonopus compressus* (broad-leaf carpetgrass), *Cynodon dactylon* (bermudagrass 'Winter Green') and *C. dactylon* × *C. transvaalensis* hybrid ('Tifgreen'), *Digitaria didactyla* (Queensland blue couch), *Paspalum notatum* (bahiagrass '38824'), *Stenotaphrum secundatum* (buffalograss 'Palmetto'), *Eremochloa ophiuroides* (centipedegrass 'Centec') and *Zoysia japonica* (zoysiagrass 'ZT-11'). From May 2002 to June 2003, control plots were irrigated with potable water and fertilised monthly. Plots irrigated with effluent received no fertiliser from May to August 2002 (deficient phase), complete fertilisers at control rates from September to December 2002 (recovery phase) and nitrogen (N) only at control rates from January to June 2003 (supplementary phase). In October 2002, the average shoot weight of plants from the effluent plots was 4% of that from potable plots, with centipedegrass less affected than the other species (relative growth of 20%). Shoot N concentrations declined by 40% in the effluent plots from May to August 2002 (1.8 ± 0.1%) along with phosphorus (P, 0.46 ± 0.02%), potassium (K, 1.6 ± 0.2%), sulfur (S, 0.28 ± 0.02%) and manganese (Mn, 19 ± 2 mg/kg) concentrations. Only the N and Mn concentrations were below the optimum for grasses. The grasses grew satisfactorily when irrigated with effluent if it was supplemented with N. Between January and June 2003 the average weight of shoots from the effluent plots was 116% of the weight of shoots from the control plots. Shoot nutrient concentrations were also similar in the 2 regimes at this time. The recycled water supplied 23% of the N required for maximum shoot growth, 80–100% of the P and K, and 500–880% of the S, calcium and magnesium. The use of recycled water represents savings in irrigation and fertiliser costs, and reductions in the discharge of N and P to local waterways. Effluent is currently about 50% of the cost of potable water with a saving of about AU$8000/ha.year for a typical sporting field.

Additional keywords: effluent, fertiliser, growth, nitrogen, phosphorus, shoot nutrient concentrations, warm-season grasses, wastewater.

Introduction

Recycled water or effluent from urban areas can be primary, secondary or tertiary treated (Snow 1997). The primary treatment involves a screening or settling to remove organic and inorganic solids. The wastewater can then be treated biologically where complex organic matter is broken down to less complex organic matter, with up to 90% of the solids removed (secondary treatment). The water can be further treated by chemical coagulation and flocculation, sedimentation, filtration, adsorption of compounds by beds of activated charcoal and reverse osmosis (tertiary treatment). Many wastewater treatment plants in Australia remove much of the nitrogen (N) and phosphorus (P) at this stage because these nutrients promote the growth of toxic algal blooms in waterways and oceans. The water can also be disinfected with chlorine, ultraviolet radiation or ozone. Typically, the concentration of organic matter in water as it is treated is reflected in the decline of the biochemical oxygen demand and total suspended solids, along with the concentrations of N and P, and counts of bacteria (Menzel *et al*. 2002).

There is increasing interest in the use of recycled water for irrigating turfgrasses and other grass species in Australia (Bond 1998). The golf industry has been using this technology for some time and parks, gardens and sporting fields can also be irrigated with effluent. The use of wastewater in Queensland is expected to rise from 30 000 to 60 000 ML in the next few years, reducing the amounts of N and P that are discharged into waterways. A study on nutrient loading in the Murray–Darling River system found that more than 25% of the nutrients entering the waterway during an average year came from wastewater treatment plants, with this value climbing to 50% in dry years (Gutteridge Haskins & Davey Pty Ltd 1991).

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Snow (1997) and Harivandi (2000, 2004) discussed the use of recycled water on grasses in the United States of America (USA) focusing on the potential of recycled water in arid states such as Texas, Arizona and California. Robert Carrow and his associates reviewed the use of recycled water in golf courses (Duncan *et al*. 2000; Huck *et al*. 2000). Municipal effluent is ideally suited for the irrigation of parks, gardens, sports fields and golf courses because many areas in northern Australia permit the continuous growth of turf species, allowing year-round use of the wastewater. Turfgrasses have dense shoots and root systems that remove nutrients and pollutants from the water, have a relatively high water use and, therefore, can utilise a large volume of wastewater. They can use the N, P and other nutrients in the water, which would normally be discharged into waterways. There are also fewer concerns about health issues compared with the use of effluent on food crops (Mujeriego *et al*. 1996).

Hayes *et al*. (1990*a*, 1990*b*) and Mancino and Pepper (1992) investigated the effects of secondary effluent on bermudagrass, *Cynodon dactylon*, in Arizona, USA, over 40 weeks. The effluent had an electrical conductivity (EC_w) of 0.65–0.91 dS/m, a sodium absorption ratio (SAR) of 3.2–4.1, 81–113 mg sodium (Na)/L, 1–36 mg N/L and 6–27 mg P/L. It was not particularly saline but had high concentrations of Na, N and P at times. The effluent increased the soil EC and concentrations of Na, N and P, but not enough to affect soil quality. The water that leached below the roots was also not degraded. Rankings of turf quality were similar in plots given potable water or effluent.

The effluent used in Arizona seemed to contain more plant nutrients than that found in northern Australia; however, the Na and salinity issues are probably similar (Menzel *et al*. 2002). We report on the effects of tertiary effluent and fertilisers on the performance of 8 tropical grasses in the Pine Rivers Shire just north of Brisbane. Control plots were irrigated with potable water and fertilised every month. Plots irrigated with effluent received no chemical fertilisers from May to August 2002 (deficient phase), complete fertilisers from September to December 2002 (recovery phase), and N only from January to June 2003 (supplementary phase). The plants irrigated with effluent were thus dependent on the wastewater for all nutrients from May to August 2002 and all nutrients except N from January to June 2003.

Materials and methods

Treatments

Experiments were conducted on 8 tropical grasses grown in 100-L bags of sand in the full sun at Murrumba Downs in Pine River Shire, north of Brisbane (27.4°S, 153.1°E). The 8 tropical grass species were the same as those used by Menzel and Broomhall (2006) and included *Axonopus compressus* (broad-leaf carpetgrass), *Cynodon dactylon* and *C. dactylon* × *C. transvaalensis* hybrids (bermudagrasses 'Winter Green' and 'Tifgreen'), *Digitaria didactyla* (Queensland blue couch), *Paspalum notatum* (bahiagrass '38824'), *Stenotaphrum secundatum* (buffalograss 'Palmetto'), *Eremochloa ophiuroides* (centipedegrass 'Centec') and *Zoysia japonica* (zoysiagrass 'ZT-11').

There were 2 irrigation and fertiliser treatments: (i) control plots irrigated with potable water and fertilised every month; and (ii) plots irrigated with effluent that received no fertiliser from May to August 2002 (deficient phase), complete fertiliser at control rates from September to December 2002 (recovery phase) and N only at control rates from January to June 2003 (supplementary phase).

The experiment was laid out in 2 blocks: the first block was irrigated with potable water and the second block with effluent (8 cultivars × 2 irrigation and fertiliser treatments), with 4–5 replicates per treatment. The cultivars were randomised in each block. It was necessary to separate the 2 irrigation and fertiliser treatments to prevent contamination of the control plots with effluent. The average shoot dry weights (after the plants were mowed to thatch level) at the start of the experiment in May were similar between the 2 blocks (treatments): 24.6 ± 1.3 g/plot in the control block and 22.1 ± 0.9 g/plot in the effluent block. Shoot nutrient concentrations were also similar between the 2 blocks before the start of the experiment [N, control 2.4 ± 0.1% *v*. effluent 2.4 ± 0.2%; P, 0.49 ± 0.03 *v*. 0.49 ± 0.02%; potassium (K), 2.7 ± 0.1 *v*. 2.7 ± 0.1%; sulfur (S), 0.43 ± 0.05 *v*. 0.42 ± 0.05%; calcium (Ca), 0.38 ± 0.04 *v*. 0.39 ± 0.04%; magnesium (Mg), 0.26 ± 0.02 *v*. 0.26 ± 0.02%; copper (Cu), 7.4 ± 0.6 *v*. 6.8 ± 0.5 mg/kg; zinc (Zn), 29 ± 2 *v*. 25 ± 2 mg/kg; manganese (Mn), 28 ± 4 *v*. 29 ± 4 mg/kg; iron (Fe), 88 ± 4 *v*. 87 ± 8 mg/kg; and boron (B), 4.6 ± 0.7 *v*. 4.1 ± 0.6 mg/kg].

The grasses were planted in October 1999 and were involved in a nutrition experiment using potable water from May to August 2001 (Menzel and Broomhall 2006). The plants were fertilised and mown to thatch level from September 2001 to April 2002, and re-randomised. There was no dethatching or aerating of the grass plots. An individual sprinkler, with variable diameter control, was installed in each bag and set to cover 100% of the surface area, delivering 90 L/h. Total available plant water in the bags was 50 mm, with the grasses receiving an irrigation of 28 mm/week.

The control plots irrigated with potable water received 1.8 g N, 0.8 g P, 2.1 g K, 1.2 g S, 0.75 g Ca and 0.18 g Mg plus trace nutrients each month from May to August 2002, which was equivalent to 72 kg N/ha, 31 kg P/ha, 84 kg K/ha, 48 kg S/ha, 30 kg Ca/ha and 7.2 kg Mg/ha; and 0.9 g N, 0.4 g P, 11 g K, 0.6 g S, 0.4 g Ca and 0.09 g Mg plus trace nutrients per month from September 2002 to June 2003, which was equivalent to 36 kg N/ha, 16 kg P/ha, 42 kg K/ha, 24 kg S/ha, 15 kg Ca/ha and 3.6 kg Mg/ha, and was 50% less than that applied from May to August 2002. The plots irrigated with effluent were fertilised from September to December 2002 at the same rate as the control plots (September 2002 to June 2003) and from January to June 2003, were fertilised with 36 kg N/ha only. A summary of the nutrients given to the 2 treatments during the 3 different phases of the experiment is provided in Table 1.

Data collection and analysis

Shoots were harvested for dry matter each month after mowing to thatch level, and shoot nutrient concentrations were determined from bulked samples of each species in May, June, July, August and December 2002, and in February and April 2003 ($n = 7$). Bulk samples of potable water and effluent were collected for chemical analyses in May, June, July and August 2002, and in March and April 2003 ($n = 6$). The data on shoot dry weight are the means (± s.e.) of 4–5 plants per treatment. The data on shoot nutrient concentrations were averaged for the different species ($n = 8$) and months ($n = 7$), and the data on water quality averaged for the different months ($n = 6$). The amounts of nutrients taken up by the shoots in the control plots were related to the amounts of nutrients in the recycled water to estimate how well the effluent was at meeting the fertiliser needs of the grasses. The amounts of nutrients taken up by the shoots were also related to the fertiliser applications in the control plots to estimate the recovery of the applied fertiliser.

Table 1. Total amounts of nutrients (kg/ha.month) applied to the tropical grasses at Murrumba Downs

Control plots were irrigated with potable water and fertilised every month. Plots irrigated with effluent received no chemical fertilisers from May to August 2002 (deficient phase), complete fertilisers at control rates from September to December 2002 (recovery phase) and nitrogen only at control rates from January to June 2003 (supplementary phase). Values for the effluent plots include amounts in the chemical fertilisers and effluent (28 mm irrigation/week)

Treatment	Nitrogen	Phosphorus	Potassium	Sulfur	Calcium	Magnesium
			May–Aug. 2002			
Potable water	72	31	84	48	30	7.2
Effluent	5.7	4.7	19	22	27	11
			Sept.–Dec. 2002			
Potable water	36	16	42	24	15	3.6
Effluent	41.7	20.7	61	46	42	14.6
			Jan.–June 2003			
Potable water	36	16	42	24	15	3.6
Effluent	41.7	4.7	19	22	27	11

Results

Weather

Mean daily maximum temperatures during the experiment ranged from 21.4°C in August 2002 to 28.6°C in December 2002 and January 2003 (Table 2). Similarly, mean daily minimum temperatures ranged from 6.0°C in July 2002 to 21.1°C in February 2003. The mean monthly rainfall ranged from 0 to 211 mm, and mean monthly evaporation from 75 to 264 mm. Temperatures (except the minimum in July 2002) and evaporation were similar to the long-term averages whereas rainfall from May 2002 to June 2003 was lower (1093 *v.* 1357 mm).

Water chemistry

The effluent and potable water had a similar pH (Table 3). In contrast, the effluent had a higher concentration of total dissolved salts (TDS) and EC_w, associated with higher concentrations of N, P, K, S, Ca, Na, chloride and bicarbonate. The EC_w of the effluent was in the range likely to affect the growth of some grasses whereas Na and chloride were at the low end of the toxic range. The Na hazard for the soil, as determined by the SAR and EC_w, of the effluent was low. The residual Na carbonate (RSC) was just above 0, with a slight excess of bicarbonate compared with Ca and magnesium (Mg) concentrations. Concentrations of N, K, Ca and Mg were low for irrigation waters whereas P was high.

Growth

Maximum shoot dry weights in the control plots occurred from October to January and minimum weights from June to September (Fig. 1). The grasses varied in their relative cold tolerance as indicated by their growth in June, July, August

Table 2. Mean daily maximum and minimum temperatures, and mean monthly rainfall and evaporation at Murrumba Downs during 2002–03 and the long-term averages

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					2002							
Max. temp. (°C)	30.2	30.2	28.5	26.8	23.4	22.0	21.7	21.4	24.8	26.1	27.0	28.6
Min. temp. (°C)	21.0	21.0	18.8	16.2	12.3	10.0	6.0	9.8	13.1	15.3	18.0	19.5
Rainfall (mm)	61	46	58	49	64	68	0	101	22	40	38	177
Evaporation (mm)	251	213	208	147	118	99	102	115	162	208	210	257
					2003							
Max. temp. (°C)	28.6	28.1	26.9	25.6	23.6	21.8	20.6	21.6	26.3	25.4	26.6	28.0
Min. temp. (°C)	19.7	21.1	18.5	16.2	12.7	10.9	9.0	10.0	12.3	14.7	16.4	20.3
Rainfall (mm)	9	211	103	51	128	81	40	26	6	66	46	140
Evaporation (mm)	264	151	158	123	96	75	93	105	201	177	228	217
					Long-term average							
Max. temp. (°C)	29.1	28.9	28.1	26.3	23.5	21.2	20.6	21.7	23.8	25.6	27.3	28.6
Min. temp. (°C)	20.9	20.9	19.5	16.9	13.8	10.9	9.5	10.0	12.5	15.6	18.0	19.8
Rainfall (mm)	158	172	139	90	99	71	63	43	35	94	97	126
Evaporation (mm)	226	182	180	135	99	90	99	127	165	195	216	233

or September compared with that in October, November, December or January. Relative growth (minimum/maximum) was 6–7% in carpetgrass, centipedegrass and buffalograss, 12% in zoysiagrass, and 17–20% in the bermudagrasses, blue couch and bahiagrass.

There were 3 different periods during the experiment with the amounts of nutrients supplied to the plants (fertilisers and effluent) varying from May 2002 to June 2003 (Table 1). The controls were irrigated with potable water and fertilised monthly from May 2002 to June 2003, whereas effluent plots received no fertiliser from May to August 2002 (deficient phase), complete fertilisers at control rates from September to December 2002 (recovery phase) and N only at control rates from January to June 2003 (supplementary phase). Ignoring the small amounts of N in the town water, the effluent plots received 66 kg N/ha.month less than the control plots in the deficient phase and 6 kg N/ha.month more in the recovery and supplementary phases. The respective differences for P (ignoring the small amount in the potable water) were 26 kg P/ha.month less than the control plots in the deficient phase, 5 kg P/ha.month more in the recovery phase and 11 kg P/ha.month less in the supplementary phase. The respective differences for K (ignoring the small amount in the potable supply) were 65 kg K/ha.month less than the control plots in the deficient phase, 19 kg K/ha.month more in the recovery phase and 23 kg K/ha.month less in the supplementary phase.

The relative growth of the grasses in the effluent plots (effluent/control) declined to less than 2–5% in October 2002 for bermudagrasses, blue couch, carpetgrass and buffalograss, zoysiagrass and bahiagrass, and 20% for centipedegrass (Fig. 1). The relative growth of the grasses in the effluent plots recovered in November and December (Fig. 1) (mean relative growth of 77% in December) when they received additional nutrients from the chemical fertilisers (Table 1). They had a relative growth of 70–179% from January to June 2003 (mean of 116%) when they were dependent on the effluent for all their nutrients, except for N (Table 1).

Shoot nutrient concentrations

There were small variations in average nutrient concentrations among the different species (data not shown). The nutrient concentrations in the control shoots (Table 4) were in the range suggested by Jones (1980), except for Ca, which was low. The shoot N concentration decreased by 40% from May to August 2002 in plants irrigated with effluent, below the suggested optimum range for grasses (Table 4). There were also declines in P (25%), K (35%), S (30%) and Mn (45%) concentrations. Shoot Ca and Mn concentrations were slightly below the optimum suggested by Jones (1980). Shoot N and K concentrations increased in plants from effluent plots from August 2002 to April 2003 whereas Ca, Mn and B concentrations decreased. In April 2003, shoot P, K, S, Ca and Mn concentrations in plants from effluent plots were lower than those recorded by the controls (Table 4), but only Ca and Mn concentrations were below the standard.

Table 3. Quality of the potable water and effluent at Murrumba Downs

EC_w, electrical conductivity of the water; TDS, total dissolved salts; SAR, sodium absorption ratio; RSC, residual sodium carbonate; N, nitrogen; P, phosphorus. Values are the mean of 6 samples (± s.e.) collected in May, June, July and August 2002, and in March and April 2003. Guidelines for the interpretation of water quality for irrigating grasses were taken from Snow (1997) and Carrow and Duncan (1998)

Measurement	Potable water	Effluent	Level expected to give slight to moderate problems	Level considered high for irrigation waters
pH	7.9 ± 0.2	8.0 ± 0.2	9.0	
EC_w (dS/m)	0.28 ± 0.01	0.62 ± 0.02	0.70–3.00	
TDS (mg/L)	180 ± 9	394 ± 11	450–2000	
Sodium (mg/L)	29 ± 1	90 ± 2	70–210	
Chloride (mg/L)	31 ± 1	80 ± 2	70–355	
Boron (mg/L)	0.1	0.1	0.7–3.0	
SAR	1.4 ± 0.1	3.8 ± 0.1	If SAR is 3–6 and EC_w is 1.2–0.3 dS/m	
Carbonate (meq/L)	0	0		
Bicarbonate (meq/L)	1.4 ± 0.1	2.4 ± 0.1	1.5–8.5	
RSC (meq/L)	–0.26 ± 0.05	0.41 ± 0.09	1.25–2.50	
Total N (mg/L)	0.30 ± 0.06	5.10 ± 1.60		23
Total P (mg/L)	0.1	4.2 ± 0.2		0.8
Potassium (mg/L)	3 ± 0.3	17 ± 2		30
Calcium (mg/L)	18 ± 1	24 ± 1		80
Magnesium (mg/L)	9.3 ± 0.4	10.2 ± 0.5		35
Sulfur (mg/L)	10.5 ± 0.2	19.2 ± 0.3		180

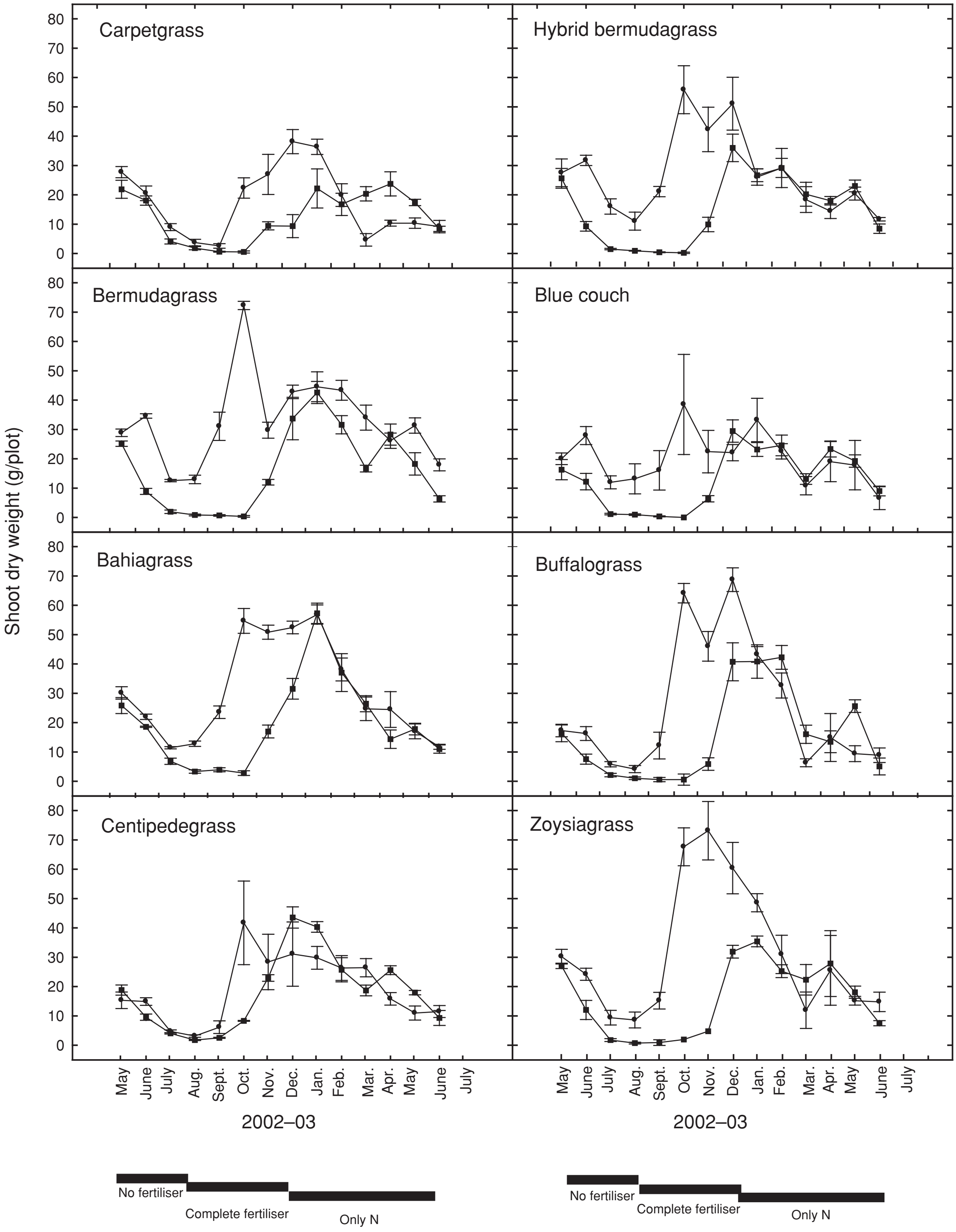

Fig. 1. Effects of effluent and fertilisers on the growth of tropical grasses at Murrumba Downs just north of Brisbane. From May 2002 to June 2003 the controls were irrigated with potable water (●) and fertilised monthly. Effluent plots (■) received no fertiliser from May to August 2002 (deficient phase), complete fertilisers at control rates from September to December 2002 (recovery phase), and nitrogen only at control rates from January to June 2003 (supplementary phase). Data are the mean (± s.e.) of 4–5 replicates per treatment. Horizontal bars show the fertiliser treatments given to the effluent plots.

Table 4. Effects of effluent and fertilisers on shoot nutrient concentrations in tropical grasses at Murrumba Downs

Effluent plots received no fertiliser from May to August 2002 (deficient phase), complete fertilisers at control rates from September to December 2002 (recovery phase) and N only at control rates from January to June 2003 (supplementary phase). Nutrient concentrations in shoots were measured at the start of each month. Data are the mean (± s.e.) of 8 species with 4–5 plants per treatment

Nutrient	Potable water	Effluent						
		May 2002	June 2002	July 2002	Aug. 2002	Dec. 2002	Feb. 2003	Apr. 2003
Nitrogen (%)	2.8 ± 0.5	3.1 ± 0.1	2.6 ± 0.1	2.0 ± 0.1	1.8 ± 0.1	2.5 ± 0.1	2.2 ± 0.2	2.9 ± 0.3
Phosphorus (%)	0.57 ± 0.12	0.60 ± 0.08	0.63 ± 0.12	0.50 ± 0.03	0.46 ± 0.02	0.53 ± 0.02	0.43 ± 0.01	0.48 ± 0.03
Potassium (%)	2.5 ± 0.3	2.5 ± 0.3	2.0 ± 0.3	1.8 ± 0.1	1.6 ± 0.2	2.3 ± 0.1	2.0 ± 0.1	2.0 ± 0.1
Sulfur (%)	0.42 ± 0.07	0.42 ± 0.11	0.35 ± 0.08	0.29 ± 0.02	0.28 ± 0.02	0.39 ± 0.03	0.33 ± 0.03	0.28 ± 0.02
Calcium (%)	0.37 ± 0.07	0.38 ± 0.10	0.40 ± 0.09	0.44 ± 0.04	0.41 ± 0.04	0.30 ± 0.03	0.28 ± 0.03	0.31 ± 0.03
Magnesium (%)	0.25 ± 0.01	0.24 ± 0.05	0.23 ± 0.08	0.24 ± 0.03	0.22 ± 0.03	0.28 ± 0.03	0.22 ± 0.02	0.25 ± 0.02
Sodium (%)	0.20 ± 0.01	0.26 ± 0.33	0.24 ± 0.32	0.20 ± 0.08	0.19 ± 0.08	0.40 ± 0.16	0.27 ± 0.12	0.25 ± 0.12
Chloride (%)	0.75 ± 0.03	0.78 ± 0.23	0.64 ± 0.24	0.60 ± 0.09	0.52 ± 0.08	1.02 ± 0.20	0.82 ± 0.16	0.78 ± 0.11
Copper (mg/kg)	8 ± 1	8 ± 1	7 ± 1	8 ± 0.4	9 ± 1	7 ± 1	6 ± 1	7 ± 1
Zinc (mg/kg)	29 ± 1	29 ± 5	25 ± 4	42 ± 7	35 ± 2	28 ± 2	32 ± 2	34 ± 4
Iron (mg/kg)	112 ± 22	87 ± 11	87 ± 10	135 ± 13	149 ± 19	73 ± 3	71 ± 7	115 ± 20
Manganese (mg/kg)	35 ± 6	30 ± 18	25 ± 15	21 ± 3	19 ± 2	16 ± 2	17 ± 3	19 ± 4
Boron (mg/kg)	9 ± 2	7 ± 2	6 ± 2	5 ± 1	13 ± 1	8 ± 1	8 ± 1	7 ± 1

Nutrient uptake

The average uptake of nutrients in the control plots (kg/ha.month) was 24.4 ± 1.8 kg N, 4.8 ± 0.3 kg P, 21.4 ± 1.2 kg K, 3.6 ± 0.5 kg S, 3.1 ± 0.4 kg Ca and 2.2 ± 0.2 kg Mg, and the average amount of nutrients applied in the effluent (kg/ha.month), based on an irrigation of 28 mm/week, was 5.7 kg N, 4.7 kg P, 19 kg K, 22 kg S, 27 kg Ca and 11 kg Mg. Thus, the effluent supplied 23% of the N, 98% of the P, 89% of the K, 611% of the S, 871% of the Ca and 500% of the Mg required for maximum shoot growth. A similar calculation showed that the recovery of nutrients from the chemical fertilisers (nutrients in control shoots/nutrients in fertilisers) was 53% for N, 24% for P, 40% for K, 12% for S, 16% for Ca and 48% for Mg. This analysis does not take into account the nutrients required for root growth or the return of some of the nutrients to the soil if the clippings remained on-site.

Discussion

Growth

Effluent and fertilisers had strong effects on the growth and mineral composition of the grasses. Species varied in their sensitivity to the treatments even though the differences were not as dramatic as in Menzel and Broomhall (2006). Centipedegrass was less sensitive to low nutrient supply than the other grasses. In October 2002, after grasses had been dependent on the nutrients in the effluent for their fertiliser needs from May to August, plant dry matter from the effluent plots weighed less than 20% of that from the control plots (Table 1). Growth recovered over the next few months when the grasses irrigated with effluent were given a general fertiliser from October to December 2002, and N from January to June 2003 (Table 1). Towards the end of the experiment in May and June 2003, growth in the effluent plots ranged from 47 to 165% of the growth in the control plots (mean of 108%).

Menzel and Broomhall (2006) examined the effects of fertilisers on the same species in Murrumba Downs, with control plots fertilised from May to September, and unfertilised plots receiving no fertiliser after May. At the end of the experiment, unfertilised plots had only 11% of the weight of the shoots of fertilised plots, with leaf N concentrations falling by 47%. There were also declines in P (20%), K (38%), S (29%) and Mg (26%), suggesting that regular applications of nutrients are required for quality turf in northern Australia.

Carrow *et al*. (2001) summarised the general behaviour of warm-season grasses to N in northern America and indicated that leaf colour increased with increasing N application. Shoot dry matter production and shoot density also increased, with a reduction at excessive N rates. In contrast, maximum rhizome, and stolon and root growth and wearability occurred at intermediate rates. There was also excessive thatch in some cultivars at very high rates of N application. The grasses in our experiment given effluent showed typical symptoms of N deficiency from May to August 2002 with less dry matter production, thinner stands and yellow leaves.

The species varied in their sensitivity to cold weather, with the relative order for increasing cold tolerance based on the relative growth of grasses in the control plots (minimum growth/maximum growth): centipedegrass = buffalograss = carpetgrass < zoysiagrass < blue couch < bermudagrass < bahiagrass < hybrid bermudagrass. The relative performance of the species was similar to that recorded in the earlier nutrition experiment at Murrumba Downs (Menzel and Broomhall 2006).

Shoot nutrient concentrations

The shoot N concentration decreased by 40% along with P, K, S and Mn concentrations from May to August 2002 (the deficient phase) in the effluent plots when they were dependent on the effluent for their fertiliser needs. The concentration of N in shoots from the effluent plots was below the optimum at the end of the deficient phase (1.8%) whereas the concentrations of P (0.46%), K (1.6%) and S (0.28%) were within the optimum range (Jones 1980). The shoot Mn concentration was also below the optimum established for turfgrasses (25–150 mg/kg) even though it is possible that acceptable growth can be achieved with lower concentrations. These results suggest that it was mainly low concentrations of N from May to August 2002 that reduced the growth in the effluent plots.

The average concentrations of N, S, Ca and Mn in the shoots from the control plots from May 2002 to June 2003 were lower than those reported by Menzel and Broomhall (2006), reflecting the 50% reduction in fertiliser applications from September 2002 to June 2003 (Table 1). The concentrations of the other nutrients were similar in the 2 experiments, suggesting over-fertilisation in the nutrition trial. The concentration of Ca in shoots from the control plots were also lower than the optima established by Jones (1980) (0.37% *v.* 0.50–1.25%) even though acceptable plant growth may occur at this concentration.

Uptake of nutrients

The shoots recovered 53% of the N supplied to the control plots, 24–48% of the P, K and Mg, and 12–16% of the S and Ca. The recovery of nutrients from the fertiliser was 2–3 times higher than in the earlier experiment of Menzel and Broomhall (2006) where the grasses received 56% more fertiliser. The effluent supplied less than 25% of the N required for maximum shoot growth, and 80–100% of the P and K. In contrast, S, Ca and Mg were in excess of plant requirements.

Hayes *et al.* (1990*a*, 1990*b*) and Mancino and Pepper (1992) found that secondary effluent provided 250 kg N/ha in their study of common bermudagrass overseeded with perennial ryegrass (*Lolium perenne*) in Arizona. The response of the grass to monthly N applications was inconsistent; N in the fertiliser and effluent were below plant needs some months and in excess at other times. In their studies, the effluent could not meet the N requirement of the turf (mainly the ryegrass) during the cooler months. In the present study, the effluent at Murrumba Downs would not be expected to meet the N requirements of the grasses during the warmer or cooler months (average uptake of 15.0–31.1 *v.* 5.7 kg N/ha in the effluent in the present experiment).

Salinity and other ions

Carrow and Duncan (1998) reported on the relative salt tolerance of warm-season turfs in the USA. Bahia, carpet, centipede and zoysiagrass were sensitive with growth reduced once the EC of a soil saturation extract (EC_{se}) was greater than 1.5 dS/m. Bermuda and buffalograss varied from very sensitive to very tolerant with an average threshold EC_{se} of 3.7 and 6.5 dS/m, respectively. Values of EC_{se} can be calculated from the EC_w using a predicted leaching fraction of the soil under irrigation and for well-irrigated situations, $EC_{se} = 1.5 \times EC_{w.}$ The average EC_w in our experiment was equivalent to an EC_{se} of 0.9, with higher values expected if few of the salts were leached below the root-zone. These data suggest that there would only be problems with very sensitive species.

High concentrations of Na can affect the behaviour of soils by increasing soil dispersibility and compaction, and by reducing the infiltration of water. Sodium hazard guidelines can be based on the SAR of the irrigation water with SARs less than 10 considered safe on most soils (Carrow and Duncan 1998). Sodium absorption ratios between 10 and 18 can cause problems on clays with high cation exchange capacities whereas SARs between 18 and 26 require intensive management on most soils. Taking into account the type of clay can derive more accurate predictions of potential Na problems with non-swelling clays such as kaolinite, and iron or aluminium oxides tolerating higher concentrations of Na than swelling types such as montmorillonite. There could be problems with SARs of 16–24 in red clays whereas black clays may fail with SARs of 6–9. Other methods of assessment take into account both the SAR and the EC_w of the irrigation water. Higher SARs can be tolerated if the EC_w is high rather than low with other salts such as Ca and Mg counteracting some of the effects of Na. A SAR of 3–6 can cause slight to moderate problems if the EC_w is lower than 0.3 dS/m (Snow 1997). The data in Table 3 suggest only a slight Na hazard in the effluent.

A positive RSC value indicates an excess of carbonate and bicarbonate over Ca and Mg, with the possibility of carbonate and bicarbonate combining with the cations. As Ca and Mg precipitate out of the soil solution, the SAR of the soil water increases. In contrast, a negative value denotes that Ca and Mg exceed the carbonate and bicarbonate ions where a build-up of Na is unlikely. Our data indicate only a slight Na hazard as determined by RSC.

Effluent can contain ions that are potentially toxic to plants, independent of their effects on soil structure. The concentrations of Na and chloride in the effluent might cause problems in sensitive species whereas the concentration of B was low (Table 3).

Calcium and Mg supplied in the effluent were in excess of plant requirements. The average amount of these nutrients in the shoots was 10–20% of that supplied in the effluent (3 *v.* 27 kg Ca/ha.month and 2 *v.* 11 kg Mg/ha.month). Excess Ca in the soil can reduce the availability of trace nutrients such as Fe, Mn and Zn (Glendinning 1999). These results suggest that it would be appropriate to monitor the concentrations of trace nutrients in grasses irrigated with effluent.

Conclusions

When given supplementary N, the growth of the tropical grasses was similar when irrigated with potable water or effluent. The use of effluent represents savings in irrigation and fertiliser costs, and reductions in the discharge of N and P to local waterways. Effluent is currently about 50% of the cost of potable water with a saving of about AU$8000/ha.year for a typical sporting field. As effluent is higher in nutrients than potable water, the extra nutrients must be accounted for in the fertilisation program. Effluent irrigation requires more frequent monitoring than programs using potable water, to check water quality, soil chemistry and changes in the amounts of nutrients being applied.

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References

Bond WJ (1998) Effluent irrigation – an environmental challenge for soil science. *Australian Journal of Soil Research* **36**, 543–555. doi:10.1071/S98017

Carrow RN, Duncan RR (1998) 'Salt-affected turfgrass sites: assessment and management.' (Ann Arbor Press: Chelsea, MI)

Carrow RN, Waddington DV, Rieke PE (2001) 'Turfgrass soil fertility and chemical problems: assessment and management.' (Ann Arbor Press: Chelsea, MI)

Duncan RR, Carrow RN, Huck M (2000) Understanding water quality and guidelines to management. *United States Golf Association Green Section Record* **36**, 14–24.

Glendinning JS (1999) 'Australian soil fertility manual.' (CSIRO Publishing: Melbourne)

Gutteridge Haskins & Davey Pty Ltd (1991) Investigation of nutrient pollution in the Murray–Darling River System. Report to the Murray–Darling Basin Commission.

Harivandi MA (2000) Irrigating turfgrasses and landscape plants with municipal recycled water. *Acta Horticulturae* **537**, 697–703.

Harivandi MA (2004) A review of sports turf irrigation with municipal recycled water. *Acta Horticulturae* **661**, 131–136.

Hayes AR, Mancino CF, Forden WY, Kopec DM, Pepper IL (1990*a*) Irrigation of turfgrass with secondary sewage effluent: II. Turf quality. *Agronomy Journal* **82**, 943–946.

Hayes AR, Mancino CF, Pepper IL (1990*b*) Irrigation of turfgrass with secondary sewage effluent: I. Soil and leachate water quality. *Agronomy Journal* **82**, 939–943.

Huck M, Carrow RN, Duncan RR (2000) Effluent water: nightmare or dream come true. *United States Golf Association Green Section Record* **36**, 15–24.

Jones JR (1980) Turf analysis. *Golf Course Management* **48**, 29–32.

Mancino CF, Pepper IL (1992) Irrigation of turfgrass with secondary sewage effluent: soil quality. *Agronomy Journal* **84**, 650–654.

Menzel CM, Broomhall P (2006) Nutrient uptake in tropical turfgrasses growing in winter in southern Queensland. *Australian Journal of Experimental Agriculture* **46**, 1217–1224.

Menzel CM, Broomhall P, Gash M (2002) Suitability of wastewater for irrigating turfgrasses. *Turf Craft International* **84**, 36–39.

Mujeriego R, Sala L, Carbo M, Turet J (1996) Agronomic and public health assessment of reclaimed water quality for landscape irrigation. *Water Science and Technology* **33**, 335–344. doi:10.1016/0273-1223(96)00436-2

Snow JT (1997) 'Wastewater reuse for golf course irrigation.' (Lewis Publishers: Boca Raton, FL)

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