Evaluation of soft leaf buffalo cultivars: renovation, mowing heights, and water use

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The University of Western Australia

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Evaluation of soft-leaf buffalograss cultivars:
renovation, mowing heights, and water use

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Ms Sharyn Burgess (summer #1) and Mr Timothy Higgott (summer #2) each contributed to this project as fixed-term research officer appointments, in the School of Plant Biology, The University of Western Australia.

Purpose of the report: Soft-leaf buffalograss (*Stenotaphrum secundatum*) is a popular amenity turfgrass in Australia, but areas planted during the past decade will soon require renovation. Experience of how this species responds to renovation was limited, so the responses of 12 buffalograss genotypes to two renovation treatments were studied. In addition, as water conservation in turfgrass management is of high importance in many regions, the influence of mowing height on water use by four warm-season turfgrass species was evaluated. Furthermore, turfgrass performance under restricted water supply of one-day-per-week watering during summer was also documented. This report details the results of these studies of turfgrass in plots and lysimeters during the hot, dry summer months of a Mediterranean-type climate at a field site in Perth, Western Australia.

Acknowledgements: This project has been funded by HAL using voluntary contributions from industry and matched funds from the Australian Government. Industry partners were: Turf Growers Association of WA, Water Corporation, Sir Walter WA Growers, Future Turf Pty Ltd (Village Green), and WA Group Pty Ltd (Empire Zoysia). For various in-kind contributions we thank Greenacres Turf Farm, Betta Turf, Turf Developments WA, Alwest Turfing, CSBP Ltd, Nick Bell and MowMaster. Plots used in the renovation experiment were established as part of HAL project TU04013, in partnership with QPI&F (now DEEDI). Sarah Rich and Bill Piasini are thanked for assistance during planting of the plots and lysimeters used in the mowing height experiment. UWA Shenton Park Field Station Staff are thanked for assistance during this study. The “UWA Turf Industries Research Steering Committee” is thanked for valuable advice and enthusiastic support.

Date: 31st March, 2012.

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Cover photograph shows members of the WA Turf Industry helping UWA Staff with renovations of the turfgrass plots at the UWA Turf Research Facility (taken by Louise Barton).
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MEDIA SUMMARY

Soft-leaf buffalograss (*Stenotaphrum secundatum*) is a popular amenity turfgrass in Australia, but information on how to renovate to remove excessive thatch is limited. We studied the responses of 12 buffalograss genotypes to two renovation treatments; either a hard rotary mow, or verti-mow with light sanding. Turfgrass firmness and recovery of growth and colour were measured. Buffalograss genotypes withstood ‘severe’ renovation using a rotary mower to cut the thatch down to 10 mm above the soil surface, although the turfgrass was brown for a few weeks until leaves re-grew. The resulting turfgrass surface was firmer than if not renovated. Verti-mowing was effective at improving firmness of old-style buffalograss, but had less effect on the soft-leaf buffalograss genotypes that started with less thatch and already firmer surfaces. Verti-mown surfaces did not brown-off. These findings demonstrate that this species is robust, which should give industry practitioners confidence when faced with renovation decisions.

Water conservation in turfgrass management is of high importance in many regions of Australia. The influence of mowing height on water use by four warm-season turfgrass species (couch, kikuyu, buffalograss, zoysia) was evaluated during the hot, dry summer months of a Mediterranean-type climate, using lysimeters installed in field plots. Water use decreased as mowing height was lowered from 50 mm to 10 mm. Mowing practices vary in different regions of Australia, so there is opportunity to reduce water use by lowering of mowing heights in some regions. Mowing height was also shown to influence the amount of clippings produced (lower height resulted in more clippings) with possible implications for green-waste management, although in many situations the clippings are returned to the turf surface.

Turfgrass performance in a sandy soil under restricted water supply of one-day-per-week watering during summer was also documented. This low watering regime resulted in brown turfgrass within a few weeks of the commencement of summer, even for the warm-season species studied here (couch, kikuyu, buffalograss, zoysia). These species were able to recover after an entire summer under this low watering regime, when irrigation was increased during autumn. If a shortage of water results in the need for one-day-per-week watering, then this will have adverse impacts on turfgrass areas, resulting in a diminished urban environment.
TECHNICAL SUMMARY

Soft-leaf buffalograss (*Stenotaphrum secundatum*) is a popular amenity turfgrass in Australia, but information on how to renovate to remove excessive thatch is limited. We studied the responses of 12 buffalograss genotypes to two renovation treatments; either a hard rotary mow, or verti-mow with light sanding. Buffalograss genotypes withstood ‘severe’ renovation using a rotary mower to cut the thatch down to 10 mm above the soil surface, although the turfgrass was brown for a few weeks until leaves re-grew. The resulting turfgrass surface was firmer. Verti-mowing was effective at improving firmness of old-style buffalograss, but had less effect on the soft-leaf buffalograss genotypes that started with less thatch and already firmer surfaces. Verti-mown surfaces did not brown-off. Both of the renovation treatments generally decreased growth; the average production of clippings (as % of controls, across all 12 genotypes) was 74% for the verti-mown treatment and only 36% for the hard rotary treatment. These findings demonstrate that this stoloniferous species is robust, which should give industry practitioners confidence when faced with renovation decisions.

Water conservation in turfgrass management is of high importance in many regions of Australia. The influence of mowing height on water use by four warm-season turfgrass species was evaluated during the hot, dry summer months of a Mediterranean-type climate, using lysimeters installed in field plots. The four species used were: couch (*Cynodon dactylon* cv. Wintergreen), kikuyu (*Pennisetum clandestinum* cv. Village Green), soft-leaf buffalograss (*Stenotaphrum secundatum* cv. Sir Walter) and zoysia (*Zoysia japonica* cv. Empire). Turfgrass water use increased as mowing height was raised. The mean water use (expressed as % pan evaporation for the four species) increased from 64% at 10 mm cutting height to 70% at 25 mm to 76% at 50 mm, in the first summer. In the second summer, the mean water use increased from 66% of pan evaporation for turfgrass cut at 10 mm to 73% for turfgrass cut at 50 mm. Mowing practices vary in different regions of Australia, so there is opportunity to reduce water use by lowering of mowing heights in some regions. Turfgrass at the lower mowing height also produced more clippings (g dry mass/m²). Compared with the plots mown at 10 mm, the total clippings produced (average of the four species) when mown at 25 mm was only 33% (summer 1) and 29% (summer 2), and when mown at 50 mm it was only 13% (summer 1) and 16% (summer 2). Thus, mowing height resulted in significant changes in shoot growth, with possible implications for green-waste management, although in many situations the clippings are returned to the turf surface.

Turfgrass performance under restricted water supply of one-day-per-week watering during summer was also documented. This low watering regime resulted in brown turfgrass within a few weeks of the commencement of summer, even for the warm-season species studied here (couch, kikuyu, buffalograss, zoysia). These species were similar in their responses in terms of declines in growth and loss of colour. Importantly, all four species were able to recover after an entire summer under this low watering regime, when irrigation was increased during autumn. If a shortage of water supply results in the need for one-day-per-week watering, this would have adverse impacts on turfgrass in parts of Australia with Mediterranean-type climates, resulting in a diminished urban environment.
INTRODUCTION

This research project addressed two topics of priority to the Australian Turfgrass Industry:
(i) Renovation techniques for thatch removal on a diverse set of soft-leaf buffalograss cultivars.
(ii) Influence of mowing height on water use by four turfgrass species (soft-leaf buffalograss, couch, kikuyu and zoysia).

Thatch accumulation can be detrimental to turfgrass surfaces (e.g. susceptibility to disease) and can diminish quality (e.g. increased surface softness). Many of the areas planted to soft-leaf buffalograss (*Stenotaphrum secundatum*) during the past decade are approaching the time when renovation will be required. Knowledge was lacking for this aspect of soft-leaf buffalograss management, and emerged as a priority given the increased popularity of this turfgrass species in many regions of Australia. Assessments were performed for responses to renovation of 11 soft-leaf types as compared with the old-style common buffalograss. In brief, recovery of the plots (growth and colour) following renovation either using a hard rotary mow or verti-mow with light sanding, as well as the influence on turfgrass firmness, were measured.

The influence of mowing height on water use and drought tolerance continues to be debated in the Australian Turfgrass Industry. Some consider that raising mowing heights during summer can enhance turfgrass performance during periods of hot weather and water deficits, whereas others argue that increased leaf area associated with higher mowing can increase turfgrass evapotranspiration (i.e. water use). Research in Western Australia had evaluated water requirements of several warm-season turfgrass species (Colmer & Short 2001; Short & Colmer 2007) and of 12 buffalograss genotypes (Duff *et al.* 2009), but mowing height was held constant in these previous experiments, as was also the case in most studies internationally (e.g. buffalograss, Atkins *et al.* 1991; *Cynodon*, Beard *et al.* 1992). Water use of nine warm-season turfgrasses increased by 3 to 15% after clipping height was raised from 30 to 60 mm (Biran *et al.* 1981). More recently, measurements of initial water extraction by several genotypes of couch have also indicated that raising of the cutting height from 20 to 50 mm increased water use (Zhou *et al.* 2009). In a study of four warm-season turfgrass species grown in lysimeters, raising of the cutting height from 20 to 50 mm also shortened by a couple of days the survival period after water was withheld (Zhou *et al.* 2012). The present study assessed the influence of mowing heights on water use by four warm-season turfgrass species; soft-leaf buffalograss (*Stenotaphrum secundatum*), couch (*Cynodon dactylon*), kikuyu (*Pennisetum clandestinum*) and zoysia (*Zoysia japonica*). Turfgrass water use was assessed using lysimeters in field plots, and turfgrass growth and quality of the plots was also measured, during two consecutive summers.

Turfgrass responses to one-day-per-week watering (one 10 mm application) emerged as a research question following Perth’s record dry 2010 winter threatened water supplies. Turfgrass performance under restricted water supply had also been an issue of importance in eastern Australia during the recent years of drought (e.g., Zhou *et al.* 2012). Therefore, as the buffalograss used in the renovation experiment in the first summer (2009/2010) did not require any further renovations, these plots were used in the second summer (2010/2011) to assess responses to one-day-per-week watering. Spare plots of the four warm-season turfgrass species (soft-leaf buffalograss, couch, kikuyu and zoysia) were also subjected to one-day-a-week watering. Growth, colour and recovery upon re-watering three-days-per-week were evaluated.
MATERIALS & METHODS

Study site and key climate data during the experimental periods in the 2009/10 and 2010/2011 irrigation periods

The experiments were conducted at The University of Western Australia Field Station in Shenton Park (31° 56.91S, 115° 47.57E), Perth, Western Australia. The soil at the field site is a Spearwood Sand (McArthur & Bettenay, 1960); a deep brown sand classified as a Basic Arenic Bleached-Orthic Tenosol (Isbell 1996). Details of physical and chemical properties of the soil have been published by Pathan et al. (2001). This region has a Mediterranean-type climate (hot dry summers and mild wet winters). Data on average monthly daily minimum and maximum air temperatures, total monthly rainfall, and total monthly evaporation, during the two irrigation periods in which the experimental work was conducted (‘summers’ of 2009/10 and 2010/11), are given in Table 1. Comparisons of these data in Table 1 with longer-term (18 or 19 years) averages of daily minimum and maximum temperatures and monthly rainfall (evaporation data were not available) for another weather station in Perth, are in Appendix 1.

Table 1. Climate data at Shenton Park, Western Australia, during the months that the experiments were conducted in the ‘summers’ of 2009/10 and 2010/11. The weather station was located adjacent to the turfgrass plots at the UWA Shenton Park Field Station.

<table>
<thead>
<tr>
<th>Month &amp; Year</th>
<th>Ave daily min air temp (°C)</th>
<th>Ave daily max air temp (°C)</th>
<th>Total monthly rainfall (mm)</th>
<th>Total monthly evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 2009</td>
<td>13.8</td>
<td>24.9</td>
<td>24.8</td>
<td>212</td>
</tr>
<tr>
<td>Dec 2009</td>
<td>16.2</td>
<td>28.8</td>
<td>0.0</td>
<td>275</td>
</tr>
<tr>
<td>Jan 2010</td>
<td>18.6</td>
<td>31.4</td>
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<td>284</td>
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<tr>
<td>Feb 2010</td>
<td>18.4</td>
<td>29.9</td>
<td>0.2</td>
<td>208</td>
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<tr>
<td>March 2010</td>
<td>18.0</td>
<td>30.6</td>
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<td>227</td>
</tr>
<tr>
<td>Nov 2010</td>
<td>14.6</td>
<td>30.0</td>
<td>0.2</td>
<td>192</td>
</tr>
<tr>
<td>Dec 2010</td>
<td>15.6</td>
<td>28.6</td>
<td>0.4</td>
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<tr>
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<td>31.0</td>
<td>0</td>
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</tr>
<tr>
<td>Apr 2011</td>
<td>15.5</td>
<td>27.0</td>
<td>22.2</td>
<td>159</td>
</tr>
</tbody>
</table>

Experiment 1: Responses of twelve buffalograss genotypes to renovation

The purpose of this experiment was to evaluate the responses of twelve buffalograss (*Stenotaphrum secundatum*) genotypes to two renovation methods designed to decrease thatch. The plots had been planted on 30/11/05 and 1/12/05 and were previously part of an earlier project (HAL Project TU04013; for details see Duff et al. 2009), and so were approximately 4 years old and with thatch build-up in most genotypes. The plots were in an area under a travelling-boom irrigator at the UWA Turf Research Facility, Shenton Park Field Station.
The experiment used a randomised split-plot design, with renovation treatments applied to main plots and genotypes as subplots: 3 renovation treatments x 12 genotypes x 2 replicates (i.e. 6 main plots, with each containing 12 subplots, with each subplot being 9 m²). The 12 genotypes of buffalograss were: GP22 (King’s Pride), Matilda, Palmetto, Sapphire (B12), Shademaster, Sir James, Sir Walter, ST 26 (AusTine), ST 91 (AusDwarf), TF01 (Jabiru), Velvet, and old-style buffalograss (WA common).

Plots had been established and then managed prior to the experiments described here as detailed in Duff et al. (2009). In brief, plots had received ‘Turf Special’ fertilizer (CSBP Ltd, Kwinana, WA) at 15 kg N/ha every 4 weeks (Turf Special contains N, P, K, S, Ca, Fe, Cu and Mn) and had been mown every two weeks at a 25 mm cutting height since spring 2007 (prior to then the cutting height had been 20 mm). The exceptions were during the cool winter months in which mowing was conducted every 4 weeks as growth had slowed. All plots received additional fertiliser in spring 2009 (45 kg N/ha of Turf Special on 25th September 2009), so as to promote vigorous spring growth prior to the renovation treatments conducted in late spring 2009. Irrigation was at 70% replacement of net evaporation summed and applied each Monday, Wednesday and Friday (i.e. three times per week), using evaporation data inputs from a weather station (WeatherMaster 200, Environdata, Australia) located adjacent to the plots and a variable-speed lateral boom travelling irrigator (Short & Colmer 2007; Barton et al. 2009a).

The renovation treatments were imposed on the 20th November 2009. Renovation treatments were: (i) control (no renovation), (ii) verti-mow in one direction, with light rotary mow to trim, rake off waste, light sanding of 5 mm, (iii) major renovation to 10 mm above ground using several passes of a rotary mower in two directions across the plots and with raking to remove waste. Plots subjected to verti-mowing were cut in one direction at 40 mm spacing and a depth of 20 mm using a Blue Bird Comber. Plots subjected to the hard rotary treatment were cut down hard, but gradually, using a rotary mower. Members of the WA Turf Industry provided in-kind support by conducting the renovations, in collaboration with UWA staff. Following renovation treatments, the plots were mown every 14 days at a cutting height of 25 mm and Turf Special fertiliser was applied at 15 kg N/ha every 4 weeks.

Recovery (i.e. re-growth and greening up of the surface) following renovation was monitored by measuring turfgrass growth, colour and surface hardness with time. Growth (dry mass of clippings produced per subplot) was measured every 14 days for a total period of 16 weeks. Growth was measured by collecting clippings from each subplot in the catcher of a 26 inch cylinder mower and transferring the clippings into paper bags for oven-drying at 65°C. Dry mass was then recorded. Turfgrass colour was measured 2 days prior to renovation, the day immediately after renovation and then every 14 days for a period of 18 weeks following renovation. Colour was measured using a CR-310 Chromameter (Minolta, Japan) and on each occasion the day after mowing. The measuring head (50 mm diameter) was pressed firmly onto turfgrass at 4 constant pre-determined positions in each subplot. Greenness can be assessed using the hue angle for the CIELAB colour space (Landschoot & Mancino 2000); the greater the value of hue angle, the greener the turfgrass. Turfgrass surface hardness was also measured 2 days prior to renovation and then at 4 week intervals for a period of 16 weeks, and again 12 months after the renovations, using a 2.25 kilogram Clegg Hammer at 4 constant pre-determined
The Clegg Hammer readings (in the units gravities) for ‘firm’ surfaces are higher than for ‘spongy’ surfaces.

Experiment 2: Water use of four turfgrass species in response to mowing height

The purpose of this experiment was to measure the influence of mowing height on water use, and this was tested on four species of turfgrass.

Plots were planted on 23rd to 25th September 2009 using small squares (~ 5 cm²) of turf cut from rolls of sod provided by local commercial growers. Prior to planting, 1.5 t/ha of pelletised fowl manure (“Turf Start”, Organic 2000, Carrabooda, WA) was applied. The small squares of turfgrass were individually pressed into the moist soil surface, in a square grid pattern of 20 cm spacing (the exception was the zoysia which is known to be relatively slow to establish, so for this species an additional small square of turf was also planted in the middle of each grid). Plots were irrigated daily during establishment. For the first 14 days irrigation volume was at 100% replacement of evaporation (split into 3 irrigation events per day), then for 21 days at 80% replacement of evaporation (split into 2 irrigation events per day), then for 21 days at 70% replacement of evaporation (one irrigation event per day). Thereafter, plots were irrigated at 70% replacement of evaporation summed and applied 3 times a week (Monday, Wednesday and Friday). During the establishment phase, Turf Special fertiliser was applied at 30 kg N/ha in weeks 2, 5, 8, 11 and 14 after planting. Thereafter, Turf Special fertiliser was applied at 15 kg N/ha every 4 weeks.

The overall design was: 4 species x 3 mowing heights x 3 replicates [3 main plots each containing 12 subplots (subplots were 9 m² each)], in a randomised design. Each main plot contained 3 subplots of each of the 4 species of turfgrass. The four species used were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter) and zoysia (Zoysia japonica cv. Empire). Within each main plot, one subplot of each species was each assigned to one of three mowing heights: 10, 25 or 50 mm. This experiment was in an area under a travelling-boom irrigator at the UWA Turf Research Facility, Shenton Park Field Station.

Weighing lysimeters were used to measure turfgrass water use at each mowing height. Each subplot housed a centrally located weighing lysimeter constructed from a PVC column (internal height 600 mm, internal diameter 210 mm) with a base that funneled to a central exit hole from which any leachate was collected in a plastic container. Each lysimeter contained surface soil from adjacent to the plots and packed to a bulk density of 1.5 g/cm³, a value similar to that of the soil in the field plots. Each lysimeter was inserted into a metal sleeve previously dug into the subplots so that the surface of the lysimeter was flush with that of the plot. This avoided “edge effects” and enabled lysimeters to be managed in the same way (planting, irrigation, fertiliser, mowing) and at the same times as the plots. Details of how the lysimeters were used to measure turfgrass water use are provided below.

Three mowing height treatments (10, 25 or 50 mm) were imposed in late December 2009, with plots (and lysimeters) then mown weekly (or every 2 weeks during the subsequent winter) at these heights for the duration of the study. Measurements were first conducted in February and
March 2010, which was about 5 months after planting, and so the lysimeters and plots were considered ‘young’ during this first summer of measurements. By the second summer (December 2010-February 2011) the lysimeters and plots had been mown for one year at the three different heights, and so were more mature and the canopy volumes were fully developed.

Growth (clippings dry mass; see Experiment 1 for details) was measured for each subplot. Clippings were collected weekly over 77 days in the summer of 2009/10 (commencing on 11th January 2010) and over 140 days in the summer of 2010/11 (commencing on 22 November 2010).

Turfgrass water use (i.e., evapotranspiration, ET) was measured by lifting each lysimeter with a portable winch that also enabled placement onto a platform balance (2 g resolution, Model B100S, Ohaus Corporation, USA) shielded from wind, to determine lysimeter weights. Each lysimeter was then re-inserted into its respective plot, and then re-weighed after 24 h, so that the change in mass provided the loss of water from the lysimeter during that time period. Lysimeter weights were measured on three consecutive days in several weeks, enabling two daily water use measurements. The first set of weight measurements were taken about 2 hours after an irrigation event and then the next irrigation was applied after the third set of weight measurements had been completed two days later. There was no rainfall during these periods of lysimeter measurements.

**Experiment 3: Performance of twelve buffalograss genotypes irrigated once weekly**

This experiment tested responses of the twelve buffalograss (*Stenotaphrum secundatum*) genotypes (see Experiment 1) to one-day-per-week watering (one 10 mm application), an issue that became a high priority for the WA turf industry, following Perth’s record dry 2010 winter threatening water supplies available to sustain the current two-day-per-week watering schedule available to homeowners. The plots used in the renovation experiment (Experiment 1) in the first summer (2009/2010) did not require any further renovations, and so were used in the second summer (2010/2011) to assess turfgrass responses to one-day-per-week watering. In addition to evaluation of the twelve buffalograss genotypes, it was also of interest to assess whether the prior renovation treatments had any influence also on performance under this low irrigation regime of one-day-per-week watering.

The plots had been maintained throughout the interim months with mowing every 2 weeks (cutting height of 25 mm) and fertilizer applications every 4 weeks (Turf Special applied at 15 kg N/ha). Irrigation of 10 mm once weekly was applied to all plots beginning on the 1st November 2010 and this regime continued for 22 weeks. Recovery of the turfgrass during a further 4 weeks was then assessed by again supplying irrigation at 70% replacement of the evaporation (summed and applied in 3 irrigation events per week).

Turfgrass colour was initially monitored weekly, then fortnightly, and again weekly during the recovery phase, using a chromameter as described in Experiment 1. Growth (clippings dry mass) was measured weekly, as described also in Experiment 1.
Experiment 4: Performance of four turfgrass species irrigated once weekly

In addition to the three main plots described for Experiment 2, a fourth main plot (12 subplots, 3 of each of the four species, arranged randomly) had also been established and maintained as described above for Experiment 2 (except all subplots here were mown at 25 mm). These plots also had the one-day-per-week watering regime imposed for the second summer (2010/11) and responses of growth and colour were assessed. The four species were as used in Experiment 2; soft-leaf buffalograss (*Stenotaphrum secundatum* cv. Sir Walter), couch (*Cynodon dactylon* cv. Wintergreen), kikuyu (*Pennisetum clandestinum* cv. Village Green) and zoysia (*Zoysia japonica* cv. Empire).

The plots had been maintained throughout the interim months with mowing every 2 weeks (cutting height of 25 mm) and fertiliser applications every 4 weeks (Turf Special applied at 15 kg N/ha). Irrigation of 10 mm once weekly was applied to all plots beginning on the 1st November 2010 and this regime continued for a period of 22 weeks. Recovery of the turfgrass during a further 4 weeks was then assessed by again supplying irrigation at 70% replacement of evaporation (summed and applied in 3 irrigation events per week). Turfgrass colour was initially monitored weekly, then fortnightly, and again weekly during the recovery phase, using a chromameter as described in Experiment 1. Growth (clippings dry mass) was measured weekly, by mowing at a cutting height of 25 mm and collection and measurement of clippings, as described in Experiment 1.

Statistical analyses of data

Analysis of Variance (ANOVA) was conducted to investigate main effects of treatments and interactions. Comparisons of means were made using least significant differences at a 5% probability level.
RESULTS

Experiment 1: Responses of twelve buffalograss genotypes to renovation

Turfgrass growth
Growth (i.e. dry mass of clippings produced) was measured over time for the 12 buffalograss (Stenotaphrum secundatum) genotypes, and Figure 1 shows the results for both renovation treatments (verti-mown with light sand or hard rotary-mown) and for control plots not renovated. The total dry mass of all clippings produced by the end of the experiment for the control plots of each genotype, and the responses to each of the renovations, are listed in Table 2.

In the control plots (no renovation), most of the genotypes did not differ in the total dry mass of clippings produced; the exceptions were ST91 which produced less clippings and three genotypes (GP22, Shademaster and Sir Walter) which produced more clippings, when compared with the other 8 genotypes (Table 2). Both of the renovation treatments generally decreased growth (Figure 1). The average production of clippings (as % of controls, across all 12 genotypes) was 74% for verti-mown treatment and only 36% for the hard rotary treatment (Table 2). An exception was Palmetto in the verti-mow treatment for which the dry mass of clippings was equal to that in its control plots (Table 2). All genotypes produced less clippings after the hard rotary treatment, when compared with the verti-mow treatment and also the controls. The most affected genotypes (Sapphire and Common) produced only about one-quarter of the clippings of those in the control plots, whereas the least affected (Sir James and Palmetto) both produced almost half as much clippings as their control plots (Table 2).

Turfgrass colour
Turfgrass colour is an important determinant of turfgrass quality (i.e. aesthetics). The visual impacts of the renovations were presented in colour pictures in Colmer et al. (2010). The hard rotary procedure resulted in a brown surface for all genotypes, and although green leaves quickly re-sprouted the surface greenness took about 4 weeks to recover to the same values of the controls and verti-mown plots (Figure 2). Verti-mown plots of some genotypes also showed a decline in colour as compared with control plots, but all verti-mown plots remained green and those which showed a small initial decline in colour recovered sooner than did the hard-rotary plots (Figure 2).

Turfgrass hardness
The hard-rotary renovation treatment succeeded in increasing the firmness of the surface of the various genotypes, and in several genotypes the hard-rotary plots persisted to be firmer than the non-renovated control plots almost 1 year after the renovation (Figure 3). The best example of this increased surface hardness in response to the hard rotary mowing was that of the common buffalograss. The verti-mow treatment resulted in less improvement in surface hardness (e.g. common buffalograss) than the hard-rotary treatment, and in most genotypes the hardness remained similar to that of the non-renovated control plots (Figure 3).
Figure 1. Cumulative clippings (dry mass g/m²) of 12 buffalograss (*Stenotaphrum secundatum*) genotypes after 3 renovation treatments, during the 2009/10 summer. Symbols: control (circles), verti-mow (squares), and hard rotary (triangles). Plots were mown at 25 mm every 14 days. The first mowing event (time 0 on 4th December 2009) was 14 days after the
Treatments were imposed (renovations were on 20th November 2009). Treatment plots were duplicated (n = 2). Error bars are not visible when smaller than the size of the symbols.

**Table 2.** Total dry mass of clippings produced by 12 buffalograss (*Stenotaphrum secundatum*) genotypes after three renovation treatments, when mown every 2 weeks for a total of 9 mowing events (the first mowing event was on 4th December 2009). Plots were mown at 25 mm and were located at Shenton Park, Western Australia (summer of 2009/10). ANOVA conducted on the data for total clippings produced (dry mass g/m²) showed significant effects (P<0.05) of genotype and renovation treatment, but no significant genotype x treatment interaction. Data for controls are means ± standard errors (duplicate plots, n = 2). For ease of treatment comparisons the data in the two renovation treatments are expressed as % of controls; dry mass g/m² for the treatments is shown in Figure 1.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>CONTROL (dry mass g/m²)</th>
<th>HARD ROTARY (% of CONTROL)</th>
<th>VERTI-MOW (% of CONTROL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td>294 ± 10</td>
<td>27</td>
<td>57</td>
</tr>
<tr>
<td>GP22</td>
<td>404 ± 10</td>
<td>34</td>
<td>63</td>
</tr>
<tr>
<td>Matilda</td>
<td>324 ± 4</td>
<td>30</td>
<td>84</td>
</tr>
<tr>
<td>Palmetto</td>
<td>342 ± 3</td>
<td>46</td>
<td>101</td>
</tr>
<tr>
<td>Sapphire (B12)</td>
<td>243 ± 4</td>
<td>26</td>
<td>72</td>
</tr>
<tr>
<td>Shademaster</td>
<td>398 ± 6</td>
<td>35</td>
<td>71</td>
</tr>
<tr>
<td>Sir James</td>
<td>267 ± 5</td>
<td>47</td>
<td>88</td>
</tr>
<tr>
<td>Sir Walter</td>
<td>405 ± 11</td>
<td>40</td>
<td>74</td>
</tr>
<tr>
<td>ST 26</td>
<td>293 ± 4</td>
<td>41</td>
<td>69</td>
</tr>
<tr>
<td>ST 91</td>
<td>128 ± 2</td>
<td>40</td>
<td>61</td>
</tr>
<tr>
<td>TF01</td>
<td>351 ± 6</td>
<td>39</td>
<td>84</td>
</tr>
<tr>
<td>Velvet</td>
<td>238 ± 7</td>
<td>30</td>
<td>51</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>307</strong></td>
<td><strong>36%</strong></td>
<td><strong>74%</strong></td>
</tr>
<tr>
<td>l.s.d (P&lt;0.05)</td>
<td>71</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>
**Figure 2.** Colour (hue angle measured with a Chromameter; greater values are more green) of 12 buffalograss (*Stenotaphrum secundatum*) genotypes after 3 renovation treatments during the 2009/10 summer. Symbols: control (circles), verti-mow (squares), and hard rotary (triangles). Controls were healthy, green turfgrass. Measurements were 2 days before and the
day after renovations (renovations were on 20th November 2009), and then every 14 days. Error bars are not visible when smaller than the size of the symbols (n = 2).

Figure 3. Hardness (gravities measured with a Clegg Hammer; surfaces with a larger value are firmer) of 12 buffalograss (*Stenotaphrum secundatum*) genotypes after 3 renovation
treatments during the 2009/10 summer and again during late spring 2010. Symbols: control (circles), verti-mow (squares), and hard rotary (triangles). Measurements were 2 days before renovations (renovations were on 20th November 2009), and then every 4 weeks. Error bars are not visible when smaller than the size of the symbols (n = 2).

Experiment 2: Water use of four turfgrass species in response to mowing height

**Turfgrass water use**
Turfgrass water use, also referred to as turfgrass evapotranspiration (ET; mm/day), was measured for four species cut at three different mowing heights. The four species were: couch (*Cynodon dactylon* cv. Wintergreen), kikuyu (*Pennisetum clandestinum* cv. Village Green), soft-leaf buffalograss (*Stenotaphrum secundatum* cv. Sir Walter) and zoysia (*Zoysia japonica* cv. Empire). Measurements were taken on a number of days during each of the two summers. Pan evaporation provides a measure of the evaporative demand for water in a particular location over a particular period of time, so daily turfgrass water use is commonly expressed as a percentage of the daily pan evaporation measured at the same time. Lysimeters and field plots were irrigated early in the morning, and measurements were taken on that same day and again on the next day.

Turfgrass water use increased as mowing height was raised, a response evident in both summers (Tables 3 and 4). The ranges of water use by the four turfgrass species at each mowing height were, during the first summer of measurements: at 10 mm mowing height, 60 - 68% of pan evaporation; at 25 mm mowing height, 65 - 74% of pan evaporation; at 50 mm mowing height, 71 - 86% of pan evaporation. In the second summer the water use values at each of the three mowing heights were: at 10 mm mowing height, 64 - 67% of pan evaporation; at 25 mm mowing height, 68 - 71% of pan evaporation; at 50 mm mowing height, 65 - 78% of pan evaporation. The grand mean for water use by the four species increased at each increase in mowing height, in both summers. These data support the hypothesis that an increased mowing height results in greater turfgrass water use, when soil water is available.

Water use differed between some of the species (Tables 3 and 4). During the first summer, the couch and soft-leaf buffalograss used less water than the zoysia (Table 3). In the second summer, the soft-leaf buffalo again used less water than the zoysia (Table 4). The variations in water use between the other species were not statistically different (i.e. differences in means were less than the l.s.d. value).
Table 3. Turfgrass water use (i.e. evapotranspiration, ET) of four turfgrass species each at three different mowing heights, expressed as % of daily pan evaporation (A class pan), and measured during the summer of 2009/10. The four species were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter), and zoysia (Zoysia japonica cv. Empire). The values given are the means ± standard errors (n = 10 measurement days, with each day the average of 3 lysimeters). Pan evaporation of the days measurements were taken ranged from 5.2 to 12 mm. Lysimeters were mown weekly and housed in field plots of the same genotype at each mowing height, at Shenton Park, Western Australia. ANOVA showed a significant main effect of mowing height (l.s.d. 5% = 5.0) and a significant effect of species (l.s.d. 5% = 5.8), but no interaction between these two factors.

Turfgrass water use (% pan evaporation)

<table>
<thead>
<tr>
<th>Species</th>
<th>Mown at 10 mm</th>
<th>Mown at 25 mm</th>
<th>Mown at 50 mm</th>
<th>Species mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch</td>
<td>63 ± 4.4</td>
<td>65 ± 3.6</td>
<td>71 ± 2.9</td>
<td>66</td>
</tr>
<tr>
<td>Kikuyu</td>
<td>64 ± 3.6</td>
<td>74 ± 2.9</td>
<td>75 ± 3.7</td>
<td>71</td>
</tr>
<tr>
<td>Soft-leaf buffalo</td>
<td>60 ± 3.5</td>
<td>68 ± 3.3</td>
<td>71 ± 3.1</td>
<td>66</td>
</tr>
<tr>
<td>Zoysia</td>
<td>68 ± 3.8</td>
<td>71 ± 3.8</td>
<td>86 ± 4.0</td>
<td>75</td>
</tr>
<tr>
<td>Mowing height means</td>
<td>64</td>
<td>70</td>
<td>76</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Turfgrass water use (i.e. evapotranspiration, ET) of four turfgrass species each at three different mowing heights, expressed as % of daily pan evaporation (A class pan), and measured during the summer of 2010/11. The four species were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter), and zoysia (Zoysia japonica cv. Empire). ET was measured on 11 days for 3 replicate lysimeters at each mowing height for each species. The values given are the means ± standard errors (n = 11 measurement days, with each day the average of 3 lysimeters, the exception was couch mown at 25 mm for which there were 2 lysimeters). Pan evaporation of the days measurements were taken ranged from 5.0 to 10.1 mm. Lysimeters were mown weekly and housed in field plots of the same genotype at each mowing height at Shenton Park, Western Australia. ANOVA showed a significant main effect of mowing height (l.s.d. 5% = 6.5) and a significant effect of species (l.s.d. 5% = 7.5), but no interaction between these two factors.

Turfgrass water use (% pan evaporation)

<table>
<thead>
<tr>
<th>Species</th>
<th>Mown at 10 mm</th>
<th>Mown at 25 mm</th>
<th>Mown at 50 mm</th>
<th>Species mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch</td>
<td>65 ± 4.7</td>
<td>69 ± 5.0</td>
<td>71 ± 4.9</td>
<td>68</td>
</tr>
<tr>
<td>Kikuyu</td>
<td>66 ± 4.3</td>
<td>71 ± 4.1</td>
<td>78 ± 4.9</td>
<td>72</td>
</tr>
<tr>
<td>Soft-leaf buffalo</td>
<td>64 ± 4.5</td>
<td>68 ± 4.4</td>
<td>65 ± 4.3</td>
<td>66</td>
</tr>
<tr>
<td>Zoysia</td>
<td>67 ± 4.0</td>
<td>70 ± 4.3</td>
<td>77 ± 5.9</td>
<td>71</td>
</tr>
<tr>
<td>Mowing height means</td>
<td>66</td>
<td>70</td>
<td>73</td>
<td></td>
</tr>
</tbody>
</table>
Turfgrass growth

Growth (i.e. dry mass of clippings produced) was also measured weekly for each individual plot housing each lysimeter, during both summer periods (Figures 4 and 5). In both summers, and for all four species, plots mown at 10 mm produced more clippings than those mown at 25 mm or at 50 mm (Figures 4 and 5). The total clippings produced (dry mass, g/m²) by the end of each experimental period is given in Tables 5 and 6. When averaged across the four species for the first summer, plots mown at 25 mm only produced 33%, and plots mown at 50 mm only produced 13%, of the clippings from plots mown at 10 mm. Similarly, during the second summer when averaged across the four species, plots mown at 25 mm produced 29%, and plots mown at 50 mm produced 16%, of the clippings from plots mown at 10 mm. Thus, the low mowing height of 10 mm resulted in a significant increase in shoot growth (i.e. amounts of clippings produced).

Considering the four species (average across all three mowing heights), in the first summer there were no significant differences amongst the species for total dry mass of clippings produced (Table 5). The plots were young (5 months old when this first summer of measurements commenced, and in particular the zoysia was still thin in places within the plots. In the second summer, zoysia produced the most clippings of the four species when mown at 10 mm, but with mowing height raised to 25 mm or 50 mm zoysia then produced less clippings than couch. Kikuyu produced surprisingly few clippings relative to couch when mown at 25 mm or 50 mm (Table 6). The different results in the second summer, as compared with the first summer, were likely due to the plots having been mown for one year at the three different heights, and so by the second summer the plots were more mature and the canopy volumes were fully developed.

Figure 4. Growth (cumulative clippings, dry mass g/m², n = 3) of four turfgrass species at 3 mowing heights over the summer of 2009/10. Symbols: 10 mm (circles), 25 mm (triangles) and 50 mm (squares). The four species were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter), and zoysia (Zoysia japonica cv. Empire). Growth was measured weekly for 77 days, commencing on 11th January 2010. Error bars are not visible when smaller than the size of the symbols.
Figure 5. Growth (cumulative clippings, dry mass g/m², n = 3) of four turfgrass species at 3 mowing heights over the summer of 2010/11. Symbols: 10 mm (circles), 25 mm (triangles) and 50 mm (squares). The four species were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter), and zoysia (Zoysia japonica cv. Empire). Growth was measured weekly for 140 days, commencing on 22nd November 2010. Error bars are not visible when smaller than the size of the symbols.

Table 5. Total dry mass of clippings (cumulative clippings, dry mass g/m², n = 3) produced by four species of turfgrass when mown weekly at three different heights for a total of 77 days (commencing on 11th January 2010). The four species were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter), and zoysia (Zoysia japonica cv. Empire). Plots were located at Shenton Park, Western Australia (summer of 2009/10). ANOVA showed a significant main effect of mowing height (l.s.d. 5% = 51), but no significant effect of species and no species x mowing height interaction.

<table>
<thead>
<tr>
<th>Species</th>
<th>Mown at 10 mm</th>
<th>Mown at 25 mm</th>
<th>Mown at 50 mm</th>
<th>Species means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch</td>
<td>418</td>
<td>217</td>
<td>137</td>
<td>257</td>
</tr>
<tr>
<td>Kikuyu</td>
<td>521</td>
<td>86</td>
<td>24</td>
<td>210</td>
</tr>
<tr>
<td>Soft-leaf buffalo</td>
<td>461</td>
<td>178</td>
<td>67</td>
<td>235</td>
</tr>
<tr>
<td>Zoysia</td>
<td>691</td>
<td>147</td>
<td>42</td>
<td>293</td>
</tr>
<tr>
<td>Mowing height means</td>
<td>523</td>
<td>157</td>
<td>68</td>
<td></td>
</tr>
</tbody>
</table>
Table 6. Total dry mass of clippings (cumulative clippings, dry mass g/m², n = 3) produced by four species of turfgrass when mown weekly at three different heights for a total of 140 days (commencing on 22nd November 2010). The four species were: couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter), and zoysia (Zoysia japonica cv. Empire). Plots were located at Shenton Park, Western Australia (summer of 2010/11; i.e. late spring-to-early autumn). ANOVA showed a significant main effect of mowing height (l.s.d. 5% = 38) and a significant effect of species (l.s.d. 5% = 33), but not interaction between these two factors.

<table>
<thead>
<tr>
<th>Species</th>
<th>Mown at 10 mm</th>
<th>Mown at 25 mm</th>
<th>Mown at 50 mm</th>
<th>Species means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couch</td>
<td>756</td>
<td>412</td>
<td>259</td>
<td>476</td>
</tr>
<tr>
<td>Kikuyu</td>
<td>830</td>
<td>199</td>
<td>82</td>
<td>370</td>
</tr>
<tr>
<td>Soft-leaf buffalo</td>
<td>864</td>
<td>259</td>
<td>147</td>
<td>423</td>
</tr>
<tr>
<td>Zoysia</td>
<td>1240</td>
<td>194</td>
<td>95</td>
<td>510</td>
</tr>
<tr>
<td><strong>Mowing height means</strong></td>
<td><strong>923</strong></td>
<td><strong>266</strong></td>
<td><strong>146</strong></td>
<td></td>
</tr>
</tbody>
</table>

Experiment 3: Performance of twelve buffalograss genotypes irrigated once weekly

This experiment tested responses of the twelve buffalograss (Stenotaphrum secundatum) genotypes to one-day-per-week watering (one 10 mm application per week). The plots used were those from Experiment 1 on renovation techniques in the first summer (2009/2010). The plots renovated the previous year did not require any further renovation, and the controls were left with their thatch, so in addition to having the twelve buffalograss genotypes, it was also of interest to observe whether the prior renovation treatments influenced performance under the low irrigation regime imposed during the second summer (2010/2011).

Turfgrass growth

Growth (dry mass of clippings produced) by each of the genotypes is shown in Figure 6. The clippings dry mass produced by the various genotypes, and with the previous renovation histories, were similar across renovation treatments – but with two exceptions. The plots of Sir Walter and Matilda that had not been renovated the previous year grew less than their previously renovated counterparts (both the hard rotary mowed and verti-mowed plots of these genotypes) (Table 4). The temporary increase in growth in all genotypes at about 63-70 days (Figure 6) resulted from rainfall (Table 1). Growth rate increased again when the plots were irrigated three-days-per-week during the 28 day recovery period (Figure 6).
Figure 6. Growth (cumulative clippings, dry mass g/m², n = 2) of 12 genotypes of buffalograss (*Stenotaphrum secundatum*) when irrigated with 10 mm one time per week during the 2010/11 summer. Each genotype had plots either not renovated (circles), renovated by hard rotary-mowing (triangles), or renovated by verti-mowing (squares), during spring in the previous year. The one time per week irrigation commenced on 1st November 2010 and
the vertical dotted line in each graph indicates commencement of the recovery period when the plots were irrigated three times per week. Error bars are not visible when smaller than the size of the symbols.

Table 7. Total clippings produced by 12 buffalograss (*Stenotaphrum secundatum*) genotypes under single weekly 10 mm irrigation, for 175 days in plots at Shenton Park, Western Australia (summer of 2010/11; commencing on 1st November 2010). Each genotype had plots either not renovated (control), renovated by hard rotary-mowing, or renovated by verti-mowing, during spring in the previous year (*n* = 2). Plots were mown weekly at 25 mm. There were no significant effects in the ANOVA of genotype or of previous renovation.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>NOT RENOVATED (CONTROL) (g dry mass m⁻²)</th>
<th>PREVIOUSLY RENOVATED HARD ROTARY (g dry mass m⁻²)</th>
<th>PREVIOUSLY RENOVATED VERTI-MOW (g dry mass m⁻²)</th>
<th>Genotype Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common</td>
<td>222</td>
<td>236</td>
<td>219</td>
<td>256</td>
</tr>
<tr>
<td>GP22</td>
<td>252</td>
<td>265</td>
<td>212</td>
<td>243</td>
</tr>
<tr>
<td>Matilda</td>
<td>122</td>
<td>250</td>
<td>232</td>
<td>201</td>
</tr>
<tr>
<td>Palmetto</td>
<td>270</td>
<td>238</td>
<td>237</td>
<td>248</td>
</tr>
<tr>
<td>Sapphire (B12)</td>
<td>237</td>
<td>232</td>
<td>216</td>
<td>228</td>
</tr>
<tr>
<td>Shademaster</td>
<td>246</td>
<td>254</td>
<td>214</td>
<td>238</td>
</tr>
<tr>
<td>Sir James</td>
<td>255</td>
<td>237</td>
<td>216</td>
<td>236</td>
</tr>
<tr>
<td>Sir Walter</td>
<td>133</td>
<td>241</td>
<td>238</td>
<td>204</td>
</tr>
<tr>
<td>ST 26</td>
<td>230</td>
<td>255</td>
<td>230</td>
<td>238</td>
</tr>
<tr>
<td>ST 91</td>
<td>282</td>
<td>235</td>
<td>221</td>
<td>246</td>
</tr>
<tr>
<td>TF01</td>
<td>231</td>
<td>260</td>
<td>198</td>
<td>230</td>
</tr>
<tr>
<td>Velvet</td>
<td>263</td>
<td>239</td>
<td>209</td>
<td>237</td>
</tr>
<tr>
<td>Treatment Means</td>
<td>229</td>
<td>245</td>
<td>220</td>
<td></td>
</tr>
</tbody>
</table>

*Turfgrass colour*

Colour declined for all genotypes following the commencement of one-day-per-week watering (Figure 7). All plots had browned off by 35-42 days after commencement of the low irrigation regime. The decline in greenness was not influenced by the previous renovation treatment, and although some genotypes lost colour a week or two later than some of the others (e.g. common buffalograss) all plots had turned brown with only a tinge of green visible by the end of December. Interestingly, when 18 mm of rain fell in January (Table 1) some plots showed a transient greening up, and for several of the genotypes (GP22, Palmetto, Sapphire, Shademaster, ST91, TF01, Velvet) this transient increase in greenness was most for plots that had been renovated the previous summer (Figure 7). All plots again lost colour and were brown for several weeks as one-day-per-week watering was continued. After 147 days, plots were watered three-days-per-week to assess recovery and all showed increases in greenness by the time measurements were terminated after 28 days at this higher irrigation regime, but almost all plots had not yet reached the initial levels of greenness present before the commencement of the one-day-per-week watering (Figure 7).
Figure 7. Colour (hue angle measured with a Chromameter; greater values are more green) of 12 genotypes of buffalograss (*Stenotaphrum secundatum*) when irrigated with 10 mm one time per week during the 2010/11 summer. Each genotype had plots either not renovated (circles), renovated by hard rotary mowing (triangles), or renovated by verti-mowing (squares), during spring in the previous year. The plots were all initially healthy and green.
turfgrass. The one time per week irrigation commenced on 1\textsuperscript{st} November 2010 and at the vertical dotted line in each graph indicates commencement of the recovery period when the plots were irrigated three times per week. Colour was initially measured every 7 days, then every 14 days, and again every 7 days during the recovery phase. Error bars are not visible when smaller than the size of the symbols (n = 2).

**Experiment 4: Performance of four turfgrass species irrigated once weekly**

A fourth main plot [12 subplots, three of each of the four species: couch (*Cynodon dactylon* cv. Wintergreen), kikuyu (*Pennisetum clandestinum* cv. Village Green), soft-leaf buffalograss (*Stenotaphrum secundatum* cv. Sir Walter) and zoysia (*Zoysia japonica* cv. Empire)] which had been planted at the same time as the plots used in Experiment 2, was also exposed to one-day-
per-
week watering during the second summer (2010/11). Growth (clippings dry mass produced) and colour were assessed.

**Growth and colour**

Cumulative production of clippings is shown in Figure 8. By the end of the measurement period, kikuyu had produced more clippings than soft-leaf buffalograss, which in turn had produced more than the couch and zoysia (Figure 8). The four species all showed a decrease in greenness within one week of the commencement of the one-day-per-week watering regime, and all plots were brown within 4 weeks (Figure 9). The responses of the four species were essentially the same, with the exception of a quicker response of soft-leaf buffalograss and zoysia to a rainfall event at 51 days, and recovery of these two species was again slightly advanced of the kikuyu and couch at the end of the summer when plots were switched from one- to three-days-per-week watering.

![Graph showing growth and colour of four turfgrass species](image-url)

**Figure 8.** Growth (cumulative dry mass of clippings, g/m\(^2\)) of four species of turfgrass receiving one irrigation of 10 mm per week and mown weekly at 25 mm, during the 2010/2011 summer. The four species were: couch (*Cynodon dactylon* cv. Wintergreen), kikuyu (*Pennisetum clandestinum* cv. Village Green), soft-leaf buffalograss (*Stenotaphrum secundatum* cv. Sir Walter), and zoysia (*Zoysia japonica* cv. Empire). One irrigation per week was imposed for a total of 154 days (commenced on 1\textsuperscript{st} November 2010), followed by 28 days of recovery (indicated by vertical dashed line; three irrigations per week). Symbols: couch (circles), kikuyu (triangles), soft-leaf buffalograss (squares), zoysia (diamonds). Error bars are not visible when smaller than the size of the symbols (n = 2).
bars are not visible when smaller than the size of the symbols (n = 3). The l.s.d.5% = 48 for means comparisons at the end of the measurement period.

**Figure 9.** Colour (hue angle measured with a Chromameter; greater values are more green) of four species of turfgrasses receiving one irrigation of 10 mm per week and mown weekly at 25 mm, during the 2010/2011 summer. The four species were: couch (*Cynodon dactylon* cv. Wintergreen), kikuyu (*Pennisetum clandestinum* cv. Village Green), soft-leaf buffalograss (*Stenotaphrum secundatum* cv. Sir Walter), and zoysia (*Zoysia japonica* cv. Empire). One irrigation per week was imposed for a total of 154 days (commenced on 1st November 2010), followed by 28 days of recovery (indicated by vertical dashed line; three irrigations per week). The plots were all initially healthy and green turfgrass. Symbols: couch (circles), kikuyu (triangles), soft-leaf buffalograss (squares), zoysia (diamonds). Error bars are not visible when smaller than the size of the symbols (n = 3).
DISCUSSION

Buffalograss renovation
Excessive thatch is considered undesirable for turfgrass surfaces as these become ‘spongy’, whereas a moderate level of thatch is desirable as it reduces surface hardness and improves wear tolerance (Beard 1973). Thatch is the layer of plant tissues that develops with age between the soil surface and the leafy surface of turfgrass. Restricting the accumulation of thatch over time is critical for maintaining quality turfgrass surfaces. Turfgrass requires ‘renovation’ to remove thatch when it becomes excessive. Mechanical techniques, such as verti-mowing, scarifying, or coring and top-dressing are commonly used. Renovation of warm-season turfgrasses has been studied for some key species (e.g., couch, Carrow et al. 1987; and kikuyu, Barton et al. 2009b), but no published data were found for soft-leaf buffalograss (Stenotaphrum secundatum).

The present study documented the benefit of using verti-mowing to renovate old-style common buffalograss, which was the genotype with most thatch when the treatments were applied (Figure 3). The soft-leaf buffalograss genotypes had firmer surfaces than the old-style common buffalograss at the time the renovations were conducted, so benefits of verti-mowing were generally not evident in surface hardness changes for the soft-leaf genotypes. A study of kikuyugrass found that verti-mowing assisted in maintaining a firmer surface, and that this method resulted in smaller declines in turfgrass colour, than other renovation techniques (Barton et al. 2009b). Buffalograss colour was also only decreased temporarily, and to a much lesser extent than the hard rotary treatment, in the present study (Figure 2).

The 12 buffalograss genotypes were shown to withstand the relatively ‘severe’ renovation technique of hard rotary mowing to cut thatch back to 10 mm above the soil surface, a practice that results in removal of substantial amounts of thatch but also removes all green leaves. This major renovation therefore results in a brown surface in the short term. Buffalograss genotypes recovered within about 4 weeks following this major renovation, although a slower-growing genotype remained ‘thin’ for a few additional weeks. Hard rotary mowing improved surface hardness (i.e. firmer) more than the verti-mowing treatment, but the resulting brown surface (albeit transient) was in stark contrast with the verti-mown plots with less disruption to the appearance of the turfgrass. The capacity of the buffalograss to re-grow a green surface in about 4 weeks after the hard rotary mowing demonstrates that this stoloniferous species can withstand this ‘severe’ renovation practice, of being of value since this renovation can be performed with a rotary mower often used by home-gardeners rather than requiring more specialist equipment. Severe renovation resulting in a few weeks of a brown surface, rather than a green surface, might not be an acceptable practice for some turfgrass areas and/or some customers.

Influence of mowing height on turfgrass water use
Water conservation in turfgrass management is of importance in many regions worldwide (Huang & Fry 1999). Choice of turfgrass types is of major importance for water conservation: warm-season turfgrass species (i.e. with C4 photosynthesis) use less water than cool-season turfgrass species (i.e. with C3 photosynthesis) (Biran et al. 1981; Huang & Fry 1999; Colmer & Short 2001; Short & Colmer 2007). Variation in water use also exists among warm-season species (e.g. Colmer & Short 2001), and even within particular species (e.g. Cynodon genotypes, Beard et al. 1992), although these differences are less than the comparison to cool-season types.
In addition to turfgrass genotype, management practices such as fertiliser regime (Barton et al. 2009a) and mowing height (Biran et al. 1981) can also influence water use by turfgrass.

The present study of four warm-season species [couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter) and zoysia (Zoysia japonica cv. Empire)] found that turfgrass water use increased as mowing height was raised (Tables 3 & 4). The mean water use (expressed as % pan evaporation) increased from 64% at 10 mm cutting height to 70% at 25 mm cutting height to 76% at 50 mm cutting height in the first summer (2009/10, Table 3). In the second summer, the difference in water use between turfgrass mown at 10 mm (66% of pan evaporation) and at 50 mm (73% of pan evaporation) was again statistically significant (2010/2011, Table 4), although the overall range was slightly less than in the first summer. These water use rates were for turfgrass not subjected to wear and with soil water available. Increased water use as cutting height was raised from 20 mm to 50 mm was also reported for a cool-season turfgrass in an outdoor field lysimeter experiment (Feldhake et al. 1983).

The water use data presented here for lysimeters housed in field plots make an important contribution to turfgrass science, especially since a widely cited paper (Biran et al. 1981) on the influence of cutting height on water use by several warm-season and cool-season turfgrass species: (i) was a short-term study lasting only 6 weeks after the cutting height was raised, and (ii) reported that differences in water use became less with time after raising the cutting height. The present work which used longer-term field studies showed increased turfgrass water use more than one year after cutting height was first raised, and thus provides novel data on water use as influenced by mowing height for four warm-season turfgrass species.

**Turfgrass performance under one-day-per-week watering**

Restrictions in water availability in many regions of Australia have focused attention on water conservation, an issue of great importance also for the turfgrass industry in many other regions of the world. Assessment of turfgrass responses to one-day-per-week watering (one 10 mm application) emerged as a priority following Perth’s record dry 2010 winter threatening water supplies available to sustain the current two-day-per-week watering schedule available to homeowners.

When irrigated with 10 mm one time per week, colour soon declined for all buffalograss (Stenotaphrum secundatum) genotypes (Figure 7). The decline in greenness was not influenced by the previous renovation treatments, but interestingly when 18 mm of rain fell in January (Table 1) some plots showed a transient greening up, and for several of the genotypes this transient increase in greenness was most for plots that had been renovated the previous summer (Figure 7). The similar declines in growth and colour of the 12 buffalograss genotypes is consistent with earlier work (Duff et al. 2009) that showed most of these genotypes have similar: (i) rates of water use, and (ii) declines in colour when subjected to a summer irrigation regime of 33% replacement of net evaporation. The declines in colour with one-day-per-week watering (present study) were more rapid than those in the earlier study with 33% replacement irrigation of net evaporation (Duff et al. 2009), as would be expected since the one application of 10 mm per week would have only replaced about 16% of pan evaporation during the warm summer months (e.g. January and February 2011). Even with 33% replacement of pan evaporation plots
had browned-off by mid-summer in that previous work (Duff et al. 2009). An important contribution of the present work was the demonstration that even under this low watering regime of 10 mm one-day-per-week, the buffalograss plots were able to increase again in greenness when re-watered.

The four species of turfgrass in the water use experiment [couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter) and zoysia (Zoysia japonica cv. Empire)] were also subjected to one-day-per-week watering and these four species also decreased in colour and turned brown within 4 weeks (Figure 10). These results for the four species and the 12 buffalograss genotypes are consistent with the findings of Short & Colmer (2007) that showed 50-60% replacement of evaporation is needed to maintain a range of warm-season turfgrass species, and that 50% replacement of evaporation (summed and applied every second day) was required to maintain soft-leaf buffalograss in an acceptable condition with modest declines in growth and colour (Duff et al. 2009). It should be noted, however, that the plots used in all these studies were not subject to wear, a factor which may increase watering requirements.

Summary
The experiments conducted during this project have resulted in the following key findings.

Experiment 1: Buffalograss (Pennisetum clandestinum) genotypes can re-grow a green surface in about 4 weeks after a ‘severe’ renovation treatment of using a rotary mower to cut the thatch down to 10 mm above the soil surface.

Experiment 2: Water use of four warm-season turfgrass species [couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter) and zoysia (Zoysia japonica cv. Empire)] increased as mowing height was raised. The increase in water use was demonstrated under field conditions and persisted one year after cutting height was first raised.

Experiments 3 and 4: One-day-per-week watering results in brown turfgrass within a few weeks of the commencement of summer. The genotypes studied [couch (Cynodon dactylon cv. Wintergreen), kikuyu (Pennisetum clandestinum cv. Village Green), soft-leaf buffalograss (Stenotaphrum secundatum cv. Sir Walter) and zoysia (Zoysia japonica cv. Empire)] were able to increase in greenness when irrigation was increased during autumn.
TECHNOLOGY TRANSFER

This project was developed, and managed in close collaboration with our industry partners. Project progress and consultation on directions, were communicated with industry groups via regular meetings of our UWA Turf Industries Research Steering Committee. Information about the project and turfgrass research at UWA is available on our web-site (www.plants.uwa.edu.au/research/turf). Updates on the project were regularly communicated to the Turf Industry via our “UWA Turf Research Program Newsletter” (distributed every 3 months). Transfer of project information to industry was also achieved by the various activities listed below.

Seminars and industry presentations
• A field open day was held on Thursday 11th February, 2010. The field day was held in conjunction with HAL Project TU04001: Kikuyu Research Project at UWA. Approximately 75 people attended the field day.
• A project update (results from summer #1) was presented as a seminar by T. Colmer to the annual general meeting of the WA Turf Growers Association (WATGA) held in Bunbury on 18th September, 2010.

Industry publications
• Our article in *Australian Turfgrass Management Journal* vol. 13.1 was picked up also by the WA Branch of Irrigation Association of Australia, and published in *The Overflow* (No. 24 Summer 2011) – the quarterly publication of Irrigation Australia (WA Region).

Media and other communication
• The field day held on Thursday 11th February, 2010 attracted media interest, especially as the UWA Institute of Agriculture assisted by organising a professional media release. Articles were published in: *Australian Horticulture* (a national magazine, March 2010); *Turf Craft International* (a national magazine, Issue 131, March-April, 2010, page 31); and *Subiaco Post* (newspaper for western suburbs in Perth, 6th March, 2010).
• The 2011 WA Turf Seminar Day resulted in a short article published in *The West Australian* (Habitat Section page 8, 28th July, 2001). Plant of the week: Lawn, by Deryn Thorpe.
• Updates on the project were regularly communicated to the Turf Industry via our “UWA Turf Research Program Newsletter” (distributed every 3 months).
• A 300-word project update was published in the 2009/2010 HAL Turf Industry Annual Report.
RECOMMENDATIONS

This project has delivered several findings, leading to recommendations.

1. Renovation. Buffalograss genotypes can withstand ‘severe’ renovation of using a rotary mower to cut the thatch down to 10 mm above the soil surface, and this resulted in a firmer surface, although the turfgrass was brown for a few weeks until leaves re-grew. Verti-mowing renovation also increased the firmness of the buffalograss with most thatch (old-style common buffalograss), but had less effect on the soft-leaf buffalograss genotypes that started with less thatch and already firmer surfaces. Verti-mown surfaces did not brown-off. These findings demonstrate that this stoloniferous species is robust, which should give industry practitioners confidence when faced with renovation decisions for soft-leaf buffalograss.

2. Water use. Water use of warm-season turfgrass species decreases as mowing height is lowered from 50 mm to 10 mm. The reduction in water use was demonstrated for four species under field conditions, and the lower water use with low-mowing was evident in two consecutive summers. Mowing practices vary in different regions of Australia, so there is opportunity to reduce water use by using lower mowing heights in some regions. Mowing height was also shown to influence the amount of clippings produced (lower height resulted in more clippings) with possible implications for green-waste management, although in many situations the clippings are returned to the turf surface.

3. One-day-per-week watering. This low watering regime results in brown turfgrass within a few weeks of the commencement of summer, even for the warm-season species studied here (couch, kikuyu, buffalograss, zoysia). These species were able to increase in greenness after an entire summer under this low watering regime, when irrigation was increased during autumn. If a shortage of water results in the need for one-day-per-week watering, then this will have adverse impacts on turfgrass areas, resulting in a diminished urban environment and likely flow-on adverse effects for the turfgrass industry and the community. The turfgrass industry should continue to engage in discussions with decision makers involved in delivery of water security for Australia’s cities and towns to ensure these planners have information on the implications to the turfgrass sector of possible future water shortages.
BIBLIOGRAPHY OF LITERATURE CITED


APPENDIX 1.
Climate statistics obtained for the period 1993/1994 to April 2012 from the Perth Metro Station (31.92 °S, 115.87 °E) for the months of interest to this study (from the Australian Bureau of Meteorology web-site www.bom.gov.au/climate/averages/tables/cw_009225.shtml).

The climate data at Shenton Park during the study period (Table 1 in main report) are in general agreement with those for the past 18 or 19 years from the Perth Metro Station (shown below). Summer rainfall during each of the two years of the present study was less at Shenton Park than the longer-term averages from the Perth Metro Station.

Climate data from the Perth Metro Station for the past 18 years (temperatures) or 19 years (rainfall), for each of the six months during which the present study was conducted. Data on monthly total evaporation were not available. Longer-term data are available for the Perth Regional Office Site (1876 to 1992), but only the more recent data from the Perth Metro Station are summarised here. The Perth Metro Station is located several kilometers from the UWA Turf Research Facility at Shenton Park.

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**APPENDIX 2.**

Diagram showing an example of subplots within one of the main plots used in Experiment 2.

The overall design of Experiment 2 was: 4 species x 3 mowing heights x 3 replicates [3 main plots each containing 12 subplots (subplots were 9 m² each)], in a randomised design. An example is given below of a randomised layout of 12 subplots (i.e. within one of the three main plots) showing four species each assigned to one of three mowing heights (10, 25 or 50 mm). Experiment 2 used three such main plots (each with independently randomised arrangements of subplots within) located under a travelling-boom irrigator at the UWA Turf Research Facility, Shenton Park Field Station, Western Australia.

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