Evaluation of a soil moisture sensor to reduce water use and nutrient leaching in turf

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University Of Western Australia

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Evaluation of a soil moisture sensor to reduce water and nutrient leaching in turf

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Purpose of the project: Excessive irrigation not only results in ‘costs’ due to extra pumping of bore water or consumption of scheme water, but can also result in high rates of nutrients leaching beyond the turf root-zone. The objective of this research was to evaluate water used and turf quality for plots irrigated via a control system linked to a soil moisture sensor as compared to ‘current best practices’ as recommended by the Water Corporation in Western Australia (in times of no watering restrictions). In addition, field lysimeters were used to evaluate water and nutrients leaching under turf. The sensor evaluated was a Holman soil moisture sensor called WaterSmart™.

Acknowledgements: We thank Horticulture Australia Limited (HAL) and Holman Industries of Western Australia for financial support of this research. Mr. Ken Cuming, a director of Watermatic Controls and inventor of the sensor, is thanked for installation of the sensors in the field plots and for advice during the study. Greenacres Turf Farm is thanked for supplying the turf used in plots at the UWA research facility. City of Stirling are thanked for providing Lanchester Park as a research site.

Date: 30th June 2003.

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1.0 Media Summary

Turf is an important part of the urban landscape in Australia, and development of ‘best management practices’ for use of water and nutrients in turf is an important economic and environmental issue.

A research project, funded by Horticulture Australia Limited (HAL) and Holman Industries, to evaluate a soil moisture sensor-controlled irrigation system was recently completed. The sensor evaluated was a Holman soil moisture sensor called WaterSmart™ developed by Cuming and Associates utilising their ‘Watermatic’ technology.

The research, conducted by Dr. Shahab Pathan and supervised by Dr. Tim Colmer in the Faculty of Natural and Agricultural Sciences, the University of Western Australia, has provided data on how much water can be saved by soil sensor-controlled irrigation systems when used in turf.

The cumulative volume of water applied to turf grass plots controlled by the WaterSmart™ soil moisture control system represented a saving of 25% in summer, when compared to water applied to plots according to current recommendations for WA homeowners (during times without watering restrictions).

Use of the soil moisture sensor-controlled system saved 100 L of water leaching per m² during 154 days (28/11/02 to 01/05/03) when compared to areas watered according to current irrigation recommendations for WA homeowners.

Turf grass quality was maintained at acceptable levels in plots controlled by the soil moisture sensor during the period of this study.

The soil moisture sensor-controlled irrigation system enabled a flexible watering schedule for turf without the need for seasonal adjustments by personnel.
2.0 Technical Summary
Watering of residential, industrial landscaping and commercial turf areas by means of fixed sprinkler systems has become commonplace and almost mandatory over the last 3 decades. Improved practice in turf irrigation may aid water conservation and minimise nutrients leaching, thus reducing the environmental impacts of turf grass culture. Excessive irrigation not only results in ‘costs’ due to extra pumping of bore water or consumption of scheme water, but can also result in high rates of nutrients leaching beyond the root-zone, therefore contributing to ground water pollution.

This study evaluated a WaterSmart™ soil moisture sensor-controlled irrigation system for improving water use in turf, in experiments conducted at two sites. Irrigation was applied to turf plots either as recommended by the WA Water Corporation (in times of no watering restrictions), or when permitted by a soil moisture sensor. In addition, field lysimeters were used to evaluate water and nutrient leaching under turf. Three replicates of each treatment were used.

The cumulative volume of water applied to the turf grass at UWA field plots controlled by the soil moisture control system represented a saving of 25% in summer of that applied to plots watered according to current recommendations (in times of no watering restrictions). Similarly, the cumulative volume of water applied during 161 days (19/12/02 to 29/05/03) to areas controlled by the soil moisture sensor at Lanchester Park was 25% less than applied to areas irrigated according to current recommendations.

The cumulative volume of leachates from lysimeters in plots at the UWA research facility under conventional irrigation method was 5.5- fold higher than the volume from lysimeters in plots under sensor-control. During the 154 day study, ~4% of the applied water drained from lysimeters in sensor-controlled plots, while ~16% drained from lysimeters in plots with conventional irrigation scheduling. Acceptable turf grass growth and quality was maintained under both treatments. The consistency between sensors was very good.

The WaterSmart™ control system demonstrated the ability to assess the watering requirements of the turf in both the UWA and Lanchester Park trial sites. The system automatically adjusted the intervals between watering cycles according to the water consumption by the turf.

3.0 Introduction
Efficient management of nutrients and water in turf grass systems is an objective of growers, managers, and society in general. Improved practices in fertiliser agronomy and irrigation scheduling have been suggested as approaches to reduce the environmental impacts of turf grass culture. Excessive irrigation not only results in ‘costs’ due to extra pumping of bore water or consumption of scheme water, but can also result in high rates of nutrient leaching beyond the root-zone, therefore contributing to ground water pollution.

Use of soil moisture sensor-controlled irrigation systems should enable automatic implementation of irrigation schedules that match supply of water to turf requirements, without managers having to under take daily monitoring or make adjustments according to changes in weather. In the metropolitan area of Perth, approximately 60% of annual household water consumption goes on watering lawns and gardens, and in summer this figures rises to almost 80% (WA Water Corporation, the Waterwise Gardening Guide). Conservation opportunities exist by using soil moisture-controlled irrigation systems for watering lawns and gardens (Connellan, 2003). Soil moisture control offers a means of preventing over irrigation, which not only wastes water but also leaches nutrients out of root zones. In the US, automatic
soil moisture tensiometer-controlled irrigation systems have operated year-round without the
need for adjustments for season or rainfall (Augustin and Snyder, 1984), and turf grass quality
can still be maintained (Snyder et al., 1984).

The objective of this research was to evaluate water used and turf quality for plots
irrigated via a control system linked to a soil moisture sensor as compared to ‘current best
practices’ as recommended by the Water Corporation in Western Australia (in times of no
watering restrictions). In addition, field lysimeters were used to evaluate water and nutrient
leaching under turf. The sensor evaluated was a Holman soil moisture sensor called
WaterSmart™ developed by Cuming and Associates utilising their ‘Watermatic’ technology.

4.0 Methods and Materials

4.1 WaterSmart™ soil moisture sensor

Holman Industries of Osborne Park, Perth, Western Australia have developed a soil moisture
sensor called WaterSmart™. The sensor, when buried in the root zone, responds to capillary
tension, which is related to the water availability in a soil. As a soil dries, tension increases
and the sensor then enables the irrigation system when the soil reaches a minimum ‘set point’.
The sensor is connected to a controller via a cable. The controller is programmed in the
normal way and the level of ‘soil wetness’ required is defined by adjusting the sensor control
dial on the controller panel. If the sensor reports the soil is moist then any scheduled irrigation
is cancelled and if the sensor reports the soil is dry then irrigation is allowed. A ‘delay’, to
ensure watering occurred before 9 am or after 6 pm, was also programmed into the controller.

A bibliography of reports that refer to the development and experience of using earlier
models of the ‘Watermatic’ sensor in recreational turf and horticultural applications is
provided in an Appendix (section 10.0).

4.2 Experiment at UWA field site

Couch grass (Cynodon dactylon (L.) Pers., cv Wintergreen) was established in six field plots,
each 3 x 3 m, on a sandy soil at the University of Western Australia Turf Research Facility in
Shenton Park (31°56' S; 115°47' E), approximately 8 km west of Perth CBD. The soil is
known locally as ‘Karrakatta sand’ (McArthur and Bettenay, 1960; Xeropsamments; USDA,
1992) cleared of natural vegetation (i.e. Banksia woodlands) in 1996. The soil had a pH (1:5,
in 0.01 M CaCl2) of 4.7, total C of 1.8%, total N of 0.08%, cation exchange capacity (CEC) of
2.2 cmol kg⁻¹, extractable P of 2.5 mg kg⁻¹, and P retention index (PRI; Allen and Jeffery,
1990) of 2.1 (for more details see Pathan et al., 2003). Plots were planted with turf rolls on 9th
January 2002 following cultural practices used by the Western Australian turf industry.

The experimental design was 2 irrigation regimes x 3 replicates = 6 plots (Figure 1).
The two irrigation regimes were: (i) 10 mm for each application (frequency was adjusted
depending on the time of year as recommended by the Western Australia Water Corporation,
during times without watering restrictions; Table 1) and (ii) soil moisture sensor-controlled
plots scheduled at 10 mm every day, but only irrigated when the sensor permitted. The
experimental units were arranged in a completely randomised design. Each plot had four
Professional pop up Rain Bird sprinklers (one in each corner), controlled by a Pro Dial
systems controller (Holman Industries, Osborne Park, WA). A WaterSmart™ soil moisture
sensor was installed into the centre of each of three plots by Cuming and Associates Pty Ltd
(Melbourne, Victoria) at a depth of 50 mm on 14th February 2002 (Figure 2).

Fertiliser (‘Horticulture Special’, Wesfarmers CSBP Limited, Kwinana, WA; N =
12.2%, P = 3.5%; K = 10.2%, Ca = 4.0% Mg = 0.4% and S = 12% all by wt) was applied at
125 kg ha\(^{-1}\) (equivalent to 15 kg N ha\(^{-1}\)) every 14 days for the first month, and then monthly for the remainder of the study. Mowing (at a height of 10 mm using a cylinder mower), commenced two weeks after laying turf, and then occurred every 14 days during summer, and then every 28 days for the remainder of the study.

Table 1: Watering frequency for turf grass in metropolitan Perth as recommended by the WA Water Corporation (during times without watering restrictions). Ten mm should be applied during each irrigation event. Source: ‘The Waterwise Gardening Guide’ by John Colwill, WA Water Corporation.

<table>
<thead>
<tr>
<th>Month</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>Every second day</td>
</tr>
<tr>
<td>February</td>
<td>Every second day</td>
</tr>
<tr>
<td>March</td>
<td>Every third day</td>
</tr>
<tr>
<td>April</td>
<td>Every fifth day</td>
</tr>
<tr>
<td>May</td>
<td>No watering</td>
</tr>
<tr>
<td>June</td>
<td>No watering</td>
</tr>
<tr>
<td>July</td>
<td>No watering</td>
</tr>
<tr>
<td>August</td>
<td>Once a fortnight (if needed)</td>
</tr>
<tr>
<td>September</td>
<td>Once a fortnight (if needed)</td>
</tr>
<tr>
<td>October</td>
<td>Every fourth day</td>
</tr>
<tr>
<td>November</td>
<td>Every third day</td>
</tr>
<tr>
<td>December</td>
<td>Every second day</td>
</tr>
</tbody>
</table>

4.3 Measurements taken from field plots at UWA research site

The cumulative volume of water applied to each plot was measured using water flow and time meters connected with the irrigation systems. The volumetric soil water content in the top 50 mm of each plot was measured at several times using a hand-held Theta probe (Delta-T devices, ML1, Cambridge, England). The probe was calibrated immediately prior to each set of measurements. In addition, soil cores at depths of 0 - 100, 100 - 200, 200 - 300, 300 - 500 and 500 - 1000 mm were taken at the end of summer (i.e. 28/02/03) and gravimetric soil water content was measured.

Thatch dry mass was measured at selected times by taking four soil cores (70 mm diameter) from each plot, and oven-drying these at 70\(^{\circ}\)C for 72 hours. The soil was then removed from the sample, and the turf dry mass recorded. Turf leaf growth was measured for clippings collected using a cylinder mower. Samples were dried at 70\(^{\circ}\) C for 72 hours, after which dry mass was recorded. Total N in sub-samples of clippings was determined using a CHN analyser (LECO, CHN 1000, MI, USA).

During summer (December, January and February), on selected harvest dates, sub-samples of clippings were collected from the center of each plot and used for measurements of leaf water content and osmotic potential of leaf sap. Leaf water content was measured by taking instant fresh mass of the leaf samples and then re-weighing the samples after being oven-dried at 70\(^{\circ}\)C for 3 days. Water content was calculated from the difference between fresh and dry mass of samples. For leaf sap osmotic potential measurement, leaf tissues were sealed in a 1.5 mL air-tight cryovial and placed in dry ice, and stored at -20\(^{\circ}\)C. Samples were thawed while still in their sealed vials, then crushed in a stainless steel press to extrude sap. The sap was then centrifuged (Micro-centrifuge, Micromax, IEC 230, MA, USA) at 10000 rpm for 30 seconds, and 10 \(\mu\)L was immediately analysed using a freezing point depression osmometer (Fiske Associates, One-Ten, MA, USA).
Figure 1: Overview of the series of replicated turf plots at the UWA research site, established to research the use of a soil moisture sensor-controlled irrigation system.

Figure 2: The soil moisture sensor positioned and ready to be buried in the root zone of turf grass at the UWA research site. The sensor is connected to an irrigation control unit.
Turf colour (i.e. greenness) was measured in situ using a Chroma meter (Minolta, CR-310, Osaka, Japan). Three representative locations were selected within each plot and the 50 mm diameter measuring cylinder head was pressed firmly down onto the canopy surface and measurements were taken. The Chroma meter was calibrated after every 12 readings, using a calibration plate (Minolta, CR-310, Osaka, Japan) following the instructions provided by the manufacturer.

4.4 Field lysimeters
Lysimeters were placed within the field plots at the UWA research site, to evaluate leachate volumes and nutrient (nitrate, ammonium and phosphate) leaching under turf. The lysimeters were PVC columns of 210 mm inner diameter and 600 mm internal length, with a 100 mm hollow base to house a container to collect leachates. Soil (top soil, 0 - 300 mm and sub-soil, 300 - 600 mm) was collected at the site from an area adjacent to the plots, air-dried for 5 days, passed through a 2.0 mm sieve, and stored at room temperature before use.

Soil was packed into each column (top 300 mm with top soil and 300 to 600 mm with sub-soil) at a bulk density (1.5 g cm$^{-3}$) as measured for the soil at the collection site in the field (Pathan et al., 2003). Each lysimeter was inserted into a 215 mm inner diameter and 700 mm deep metal sleeve, previously dug into the field plots. The surface of each lysimeter was flush with that in the plots, to avoid edge effects. Access holes (40 mm diameter) were located at 5 depths (100, 200, 300, 400 and 500 mm) and holes were sealed using waterproof tape. The base of the column contained a 52-µm polyester filter and a small wad of glass wool, funnelled into a central exit point from which leachates were collected in a plastic container located under each lysimeter. Each lysimeter was planted with couch grass (*Cynodon dactylon* (L.) Pers., cv Wintergreen) as a turf-roll on 31/10/02. Fertiliser and irrigation were as given to the field plots (section 4.2).

4.5 Measurements taken from field lysimeters
Volumetric soil water content in lysimeters was measured at selected times using a hand-held Theta Probe (Delta-T Devices, ML1, Cambridge, England) inserted via the access holes at different depths (100, 200, 300, 400 and 500 mm) and into the surface 50 mm. The probe was calibrated immediately prior to use and access holes were re-sealed using waterproof tape after each measurement.

Leachates in a plastic container under each lysimeter were collected weekly, over 154 days (28/11/02 to 01/05/03). The volume of leachates from each lysimeter was measured, filtered (0.45 µm) and stored frozen until analyses for nitrate, ammonium and phosphate. Some samples were lyophilised in order to concentrate them 10- to 20-fold (FD4 Freeze Dryer, Heto, DK 3450, Allered, Denmark), so that the low concentrations of ions could be detected. Nitrate was measured using the hydrazinium reduction method (Kamphake et al., 1967) and NH$_4^+$ using a modified berthelot indophenol reaction (Searle, 1984); both were linked to a segmented flow auto analyser (Skalar, SAN$^+$ Plus System, Breda, the Netherlands). Phosphate was measured using the malachite green oxalate method (Motomizu et al., 1983) and a spectrophotometer (Shimadzu, UV 1601, Kyoto, Japan). Cumulative leaching of mineral N (NO$_3^-$ plus NH$_4^+$) and P were calculated from the concentrations in, and volumes of, leachates. At harvest (01/05/03) after 154 days of treatment, shoots were snipped off the lysimeters, and then the rhizomes and roots were washed from the soil. Samples were dried at 70º C for 72 hours, after which dry mass was recorded.
4.6 Experiment at Lanchester Park, City of Stirling, WA
Lanchester Park, City of Stirling is approximately 5 km North-West of Perth CBD. Turf quality and water use in larger areas of turf (i.e. ~720 m², each section/station) under sensor-control were evaluated (Figure 3). Each station had 7 Hunter sprinklers (∼16 m radius and flow rates 5.44 L second⁻¹), controlled by a Water Smart™ controller (Holman Industries, Osborne Park, WA). A soil moisture sensor (Water Smart™) was installed into each of three areas on 12th December 2002 by Cuming and Associates Pty Ltd (Melbourne, Victoria) at a depth of 50 mm. Irrigation regime was imposed from 19th December 2002 as described in section 4.2 on three areas under sensor-control and three areas under conventional scheduling. Fertiliser and other cultural practices were as current City of Stirling practices for maintenance of ‘passive’ turf reserves.

4.7 Measurements taken from Lanchester Park
The cumulative volume of water applied to turf controlled by each section was measured using time meters connected with the irrigation systems for a period of 161 days (commenced on 19th December 2002). The volumetric and gravimetric soil water content was measured at several times (19/12/02, 23/01/03, 28/02/03, 27/03/03, 01/05/03 and 29/05/03) as described in section 4.3. Turf ‘greenness’ was measured using a chroma meter (Minolta, CR 310, Japan) as described in section 4.3.

4.8 Data analyses
Statistical analyses of the data involved one-way analyses of variance, and means were compared using Fisher’s protected LSD at the 5% level of significance.

5.0 Results
5.1 Water used and soil water content
The amounts of water applied over 12 months (April 2002 to March 2003) to plots at the UWA research facility are presented in Figure 4. The total volume of water applied during summer (December to February) to plots controlled by the soil moisture sensor was 25% less than applied to those irrigated according to the WA Water Corporation watering schedule during times without watering restrictions (Figure 4). When the period between late spring and early autumn is considered (October 2002 to April 2003) the volume of water applied to sensor-controlled plots was 34% less than applied to the plots with conventional irrigation scheduling. Similarly, cumulative volume of water applied during 161 days (19/12/02 to 29/05/03) at Lanchester Park, to areas controlled by the soil moisture sensor was 24.7% less than applied to those areas irrigated according to the WA Water Corporation watering schedule (Figure 5).

For the plots at UWA, the sensor system permitted irrigation events twice a week during summer (December to February) and weekly in autumn (March to May), and automatically cancelled all irrigations during winter (June to August) or early spring (September). During May 2002, rainfall was low (49.2 mm) compared to long-term averages (122.7 mm), therefore the sensor system permitted irrigation events on three occasions while the conventional system was turned off (Figure 4). Sensors automatically terminated irrigation events after 6 to 8 mm had been applied, depending on the delay between the sensor’s enable point and the next schedule opportunity.

The volumetric soil water content was measured at selected times during the study. At the end of summer (28/02/03) the soil water contents were 1.8- to 4.1-fold lower at different
depths (0 to 500 mm) in field lysimeters in plots controlled by the soil moisture sensor when compared to the values in the conventionally irrigated lysimeters (Figure 6). For example, volumetric soil water content in the top 50 mm was 10.4% in lysimeters in plots with sensor-control and 19.0% in lysimeters under the conventional system (Figure 6). Similarly, volumetric soil water contents in top 50 mm zone at Lanchester Park were 1.2- to 2.5-fold lower in areas controlled by the soil moisture sensor compared with areas under the conventional system, when measurements were taken on 6 selected days (Figure 7). Furthermore, at the end of summer at both sites the gravimetric soil water contents were 2- to 3-fold lower in the soil profile (0 to 1000 mm depth) under areas controlled by the moisture sensor when compared to the values in the areas under conventional irrigation control (data not shown).

5.2 Water and nutrient leaching
The amounts of water leached during 154 days (28/11/02 to 01/05/03) are presented in Figure 8a. The cumulative volumes of leachates from lysimeters in plots under the conventional irrigation method were 5.5- fold higher ($P<0.05$) than the volumes from those in plots under sensor-control (Figure 8a). During the 154 day study, ~4% of the applied water drained from lysimeters in sensor-controlled plots, while ~16% drained from lysimeters in plots irrigated according to the conventional irrigation system. Leaching of water from lysimeters in plots under sensor-control was occurred only after rainfall (Figure 8a). Use of the soil moisture sensor-controlled system saved 100 L of water leaching per m² during 154 days (28/11/02 to 01/05/03), when compared to lysimeters watered according to current irrigation recommendations for WA homeowners.

The amount of nitrogen leached from both irrigation treatments were low, and represented 1.1% (equivalent to 0.83 kg N ha$^{-1}$) of the total N applied to the conventional irrigation, and 0.3% (equivalent to 0.22 kg N ha$^{-1}$) of the total N applied to the sensor controlled irrigation treatment (Figure 8b). Phosphorus leaching was also low, and did not vary between irrigation treatments (Figure 8c). After 154 days the cumulative P leached from lysimeters was less than 3.2% (equivalent to 0.70 kg P ha$^{-1}$). It is not clear from this study whether the fertiliser, or pools already present in the soil, is the source of the N and P leached. Furthermore, nutrient leaching may have been greater if the study had been extended to include the winter months when rainfall is greater.

5.3 Turf colour, growth and tissue N concentration
Turf colour is an important characteristic since it is often associated with the quality of the surface. The turf greenness was reduced by 15 to 19% ($P<0.05$) in sensor-controlled plots when compared to the conventionally irrigated plots, when sampled during summer (December to February) at the UWA field site (Figure 9). However, this reduction was not picked up by the naked eye (Figure 10). During, winter and spring, there were no significant differences in greenness between plots in the two irrigation treatments. However, greenness had declined during winter in all plots (Figure 9), as is common for couch grass in metropolitan Perth. Turf greenness was significantly increased at Lanchester Park under both irrigation regimes when compared to initial values (Figure 11).

The cumulative clipping production was 18% lower in sensor-controlled plots than in conventionally irrigated plots during the 154 day study (28/11/02 to 01/05/03) at the UWA field site (Figure 12). Thatch height and dry mass did not differ between plots in the two irrigation treatments (Table 2). For the turf in lysimeters, the total dry mass of shoot (leaf plus rhizome) and root produced by the end of the 154 day study did not differ between lysimeters
in plots irrigated via the soil moisture sensor-controlled system or conventional system (Table 3).

The concentration of total N in leaf tissue of turf grown at the UWA research facility was not significantly different between samples from plots irrigated using the two irrigation systems. The average (± standard errors) concentrations of N in leaf tissues (% by dry mass) in summer (i.e. December to February) and autumn (i.e. March to May) were 1.9 ± 0.2 and 2.1 ± 0.3, respectively.

Table 2: Thatch height and thatch dry mass for turf grown in plots at the UWA research site with irrigation scheduled via a soil moisture sensor or conventional system. Samples were taken on the dates indicated. Data given are means of 3 replicates ± standard errors. L.s.d = Least significant difference; n.s = not significant.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Thatch height (mm)</th>
<th>Thatch mass (g m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Sensor-controlled</td>
</tr>
<tr>
<td>14/02/02</td>
<td>13.6 ± 0.32</td>
<td>13.9 ± 0.28</td>
</tr>
<tr>
<td>02/05/03</td>
<td>25.8 ± 0.96</td>
<td>25.5 ± 0.43</td>
</tr>
</tbody>
</table>

Table 3: Total shoot (leaf plus rhizomes) and root dry mass for turf grown in field lysimeters in plots with irrigation scheduled via a soil moisture sensor or conventional system. Lysimeters were harvested after 154 days of treatments (28/11/02 to 01/05/03). Total shoot mass does not include mass of clippings produced during the period. Data given are means of 3 replicates ± standard errors. L.s.d = Least significant difference; n.s = not significant.

<table>
<thead>
<tr>
<th>Days</th>
<th>Total shoot dry mass (g m⁻²)</th>
<th>Total root dry mass (g m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Sensor-controlled</td>
</tr>
<tr>
<td>0 (Initial)</td>
<td>1687 ± 68</td>
<td>1688 ± 64</td>
</tr>
<tr>
<td>154 (At harvest)</td>
<td>4364 ± 221</td>
<td>4195 ± 544</td>
</tr>
</tbody>
</table>
Figure 3: Overview of the Lanchester Park Trial Site, City of Stirling, Western Australia.

Figure 4: A comparison of the amounts of water applied on a monthly basis for a soil moisture sensor-controlled system and ‘current best practices’ conventional method to turf plots at the UWA research facility. Monthly totals for evaporation and rainfall during the study were from an Automatic Weather Station located 500 m from the plots. Data on water applied are means of 3 replicates ± standard errors (error bars not visible when smaller than the size of symbols). The 12 month study was conducted from April 2002 to March 2003.
Figure 5: The amounts of water applied to areas of turf at Lanchester Park on a cumulative basis. A comparison of the soil moisture sensor-controlled system and conventional method is given, for the period 19th December 2002 to 29th May 2003 (161 days). Data given are means of 3 replicates ± standard errors (error bars not visible when smaller than the size of symbols).

5.4 Turf water relations
Leaf water content of turf grown in the sensor-controlled plots at the UWA research facility and sampled during summer was 4 to 9% lower than in plots under conventional irrigation, although these slight differences were not statistically different (Table 4). Leaf sap osmotic potential of turf grass grown in the sensor-controlled plots was 21 to 38% more negative than in the plots irrigated via the conventional method, when sampled during summer (Table 4). Leaf water content and osmotic potential fully recovered in sensor-controlled plots during autumn (data not shown).

Table 4: Leaf tissue water content and sap osmotic potential for turf grown in plots at UWA research facility with irrigation scheduled via a soil moisture sensor or conventional system. Samples were taken during summer (i.e. December, January and February) in Western Australia. Data given are means of 3 replicates ± standard errors. L.s.d = Least significant difference; n.s = not significant.

<table>
<thead>
<tr>
<th>Month</th>
<th>Leaf water content (ml g⁻¹ dry wt)</th>
<th>Leaf sap osmotic potential (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Sensor-controlled</td>
</tr>
<tr>
<td>December</td>
<td>1.74 ± 0.04</td>
<td>1.65 ± 0.06</td>
</tr>
<tr>
<td>January</td>
<td>1.44 ± 0.08</td>
<td>1.31 ± 0.02</td>
</tr>
<tr>
<td>February</td>
<td>1.47 ± 0.04</td>
<td>1.41 ± 0.07</td>
</tr>
</tbody>
</table>

** significant at the 0.01 probability level
***significant at the 0.001 probability level.
Figure 6: Volumetric soil water contents at different depths (50, 100, 200, 300, 400 and 500 mm) in lysimeters in field plots with irrigation controlled by a soil moisture sensor or ‘current best practices’ conventional method. Measurements were taken at the beginning of the treatments (28/11/02; initial) and after 92 days of treatments (28/02/03; end of summer). Data given are means of 3 replicates ± standard errors.

Figure 7: A comparison of volumetric soil water content under turf areas with irrigation by scheduled a soil moisture sensor-controlled system or ‘current best practices’ conventional method, at selected times during 161 days (19/12/02 to 29/05/03) at Lanchester Park. Measurements were taken in the top 50 mm using a hand-held Theta probe. Data given are means of 3 replicates ± standard errors.
Figure 8: The amounts of water (a), mineral nitrogen (b), and phosphate (c) leached from field lysimeters in turf plots at the UWA research facility, during 154 days on a weekly basis. A comparison of the soil moisture sensor-controlled system and conventional method is given, for the period 28th November 2002 to 1st May 2003. During the period total applications of N and P were 75 and 22 kg ha$^{-1}$, respectively. Data given are means of 3 replicates ± standard errors (error bars not visible when smaller than the size of symbols).
Figure 9: Greenness of turf grown in plots at the UWA research facility with irrigation controlled via a soil moisture sensor or conventional methods, for 12 months (April 2002 to March 2003). Measurements were taken using a chroma meter. Data given are expressed as % of initial values at the commencement of treatments (day before sensor installation i.e. 13th February 2002). Data given are means of 3 replicates ± standard errors.

Figure 10: Visual appearance of turf in plots with irrigation controlled via a soil moisture sensor (right hand side) or conventional methods (left hand side). Photos were taken at the end of summer (i.e. 28/02/03) at the UWA research site.
Figure 11: Greenness of turf at Lanchester Park with irrigation controlled via a soil moisture sensor or conventional methods, for 161 days (19/12/02 to 29/05/03). Measurements were taken using a chroma meter. Data given are expressed as % of initial values at the commencement of treatments (day before sensor installation i.e. 18th December 2002). Data given are means of 3 replicates ± standard errors.

Figure 12: The cumulative dry mass of clippings from turf plots at the UWA research facility irrigated with control via a soil moisture sensor or conventional methods. Measurements were taken during 154 days (28/11/02 to 01/05/03). Plots were mown at 10 mm using a cylinder mower. Data given are means of 3 replicates ± standard errors.
6.0 Discussion
Use of the soil moisture sensor-controlled system saved 25% of water applied to turf during summer when compared to plots watered according to ‘current best practices’ as recommended for WA homeowners (during times without watering restrictions) (Figures 4 and 5). The ‘current best practice’ conventional method applied 64 to 75% of evaporation and the soil moisture sensor-controlled system applied 48 to 53%, during summer (December to February). The present findings are consistent with those of Short (2002); irrigation requirements during summer in Perth before declines in growth or colour were >10%, ranged from 40 to 51% of net evaporation for couch grass (*Cynodon dactylon* (L.) Pers., cv. ‘Wintergreen). It is important to note that the plots were not subjected to traffic stress, and traffic can increase turf water requirements (Carrow and Petrovic, 1992).

The cumulative volumes of leachates from lysimeters in plots under sensor-control were lower than the volumes from lysimeters in plots under the conventional method (Figure 8a), due to less water being applied to plots under the sensor-controlled system (Figure 4). Furthermore, soil water content was lower in plots under the sensor-controlled system when compared to the conventional system, when sampled at the end of summer (Figure 6). The ‘draw down’ of soil water during summer under sensor-controlled plots (i.e. use of stored soil water) lowered the need for irrigation inputs (Figure 4), and reduced the potential for water leaching below the root zone under this system (Figure 8).

The relatively low level of mineral N (NO\(_3^-\) plus NH\(_4^+\)) leached under both treatments (equivalent to 0.3 to 1.1% of total N applied) in the present study (Figure 8b) indicates that the fertiliser regime used supplied N at a rate and frequency suitable for the demand and uptake capacity of the turf. Under turf, leaching losses as high as 53% of applied N have been observed, but generally are less than 10% (Petrovic, 1990). Thus, N leaching from turf, when managed appropriately, is generally considered not to be a threat to groundwater quality (Geron et al., 1993; Snyder et al., 1984). Phosphorus leaching under turf is considered to be a potential problem only on some soil types and when high rates of soluble sources and high irrigation are applied (Shuman, 2001). In the present study, only small amounts (equivalent to 1.6 to 3.2%) of total applied P leached under both treatments (Figure 8c), and these slight differences in cumulative P leaching were not statistically significant for lysimeters in plots under sensor-controlled or conventional systems.

Total clippings produced were reduced by 18% in sensor-controlled plots, when compared to plots irrigated conventionally (Figure 12). Biran et al. (1981) found that reducing irrigation frequency (from every 2\(^{nd}\) day to every 5\(^{th}\) - 7\(^{th}\) day) decreased clippings dry mass by up to 20% for several C\(_4\) genotypes. In the present study, thatch and root dry mass were not different between plots in the two irrigation treatments. There was no significant effect of irrigation treatments on leaf tissue N concentration, and the leaf tissue concentrations of N were all regarded as sufficient for turf (Turner, 1993).

Colour is an important quality characteristic in turf and is also considered to be a good indicator of plant health (Beard, 1973). Leaf ‘firing’ and colour loss are both characteristics of drought stress (Huang et al., 1997). Irrigations via soil sensor-controlled systems in the present study reduced canopy greenness by 15 to 19%, when compared to plots irrigated conventionally (Figure 9), however these differences were not apparent to the naked eye.

Leaf water content is considered to be a good indicator of plant responses to water deficits (Huang et al., 1997). Turf in sensor-controlled plots showed slight declines in leaf water content, although these were not statistically different (Table 4). For plots irrigated via sensor control, osmotic potential of leaf sap was 21 to 38% more negative than values for
leaves from plots watered conventionally (Table 4). Osmotic adjustment is the net accumulation of solutes per unit of tissue water (Hsiao et al., 1976), and turf grass has been reported to accumulate sugars, amino acids (Youngner, 1985) and glycinebetaine (Short, 2002) during water deficits. These data indicate that during summer, turf in plots with irrigation controlled by the sensor was experiencing mild water deficits.

The results from the present study support the notion suggested by Quackenbush and Phelan (1965) that water savings could be made with little loss in turf quality by allowing short periods of water stress between irrigations.

7.0 Technology Transfer
The project involved close links with industry representatives via meetings of the ‘UWA Turf Industries Research Steering Committee’. The researchers interacted closely with our industry partner throughout the project. Information on the trial is given on our web site: http://www.fans.uwa.edu.au/research_centres/turf_research_program. Our involvement in activities for extension of results from this study are listed below.

7.1 Field days and site visits
(i) Launch of the WaterSmart™ sensor system by Senator Sue Knowles, representing the Hon Ian Macfarlane, Minister for Industry, Tourism and Resources (25/02/03). Held at the UWA field site and attended by ~55 guests from industry, research and government organisations.

(ii) A field visit was provided for delegates attending the Turf Grass Association (WA Region) Field Tour (07/05/03).

(iii) The field site has been visited by other researchers (e.g. Dr. Don Loch, Department of Primary Industries, Queensland; Professor Bob Carrow, University of Georgia, USA and Ms Lisa Fear, Investment Director, Foundation Capital, Perth).

7.2 Presentations at conferences

7.3 Popular press and publications
(i) “Water control on tap” by Deryn Thorpe. The West Australian, 08/03/03.

(ii) “Smart watering sensor may cut usages in half”. Western Suburbs Weekly, 25/03/03.

(iii) “Holman Industries Launches WaterSmart™”. Quarterly Publication of The Irrigation Association of Australia (WA Region), Summer 2003.

(iv) An “Editorial” on our research was written by Nick Bell. Turf Grass Times (WA Turf Grass Association Newsletter), Volume 4: Issue 1, May 2003.

(v) We have submitted a paper for publication in the Industry Journal ‘Irrigation Australia’.
(vi) We plan to prepare a scientific paper for submission an International peer-reviewed journal in the near future.

8.0 Recommendations

Irrigation water savings of 25% were obtained during summer in the two trial sites using the soil moisture sensor-controlled system in comparison to a ‘current best practice’ irrigation schedule. Turfgrass quality was maintained at acceptable levels in plots controlled by a soil moisture sensor during the period of this study, although it is important to note that the plots were not subjected to wear. The soil moisture sensor-controlled irrigation system enabled a flexible watering schedule for turf without the need for daily monitoring or seasonal adjustments by personnel. The sensor-controlled system at the UWA site was left turned on for one year, and it automatically cancelled all irrigations during winter and responded to dry periods in autumn and spring by permitting irrigations. The three replicate sensors gave close agreement indicating reliable and consistent performance. Furthermore, the amounts of water saved for a turf area with irrigation controlled by WaterSmart™ sensors was almost identical for the experimental plots at the UWA site and the larger areas at Lanchester Park.

The results are promising with respect to water consumption. Turf managers that choose to use a soil moisture sensor-controlled system need to ensure the sensor(s) are installed properly and in the most appropriate location(s) for the area being managed. Further studies to evaluate sensor-controlled systems over a longer periods (e.g. several years), or industry experience, are required to gain knowledge on the long-term performance of sensors.

9.0 Literature cited


10.0 Appendix

A bibliography of reports that refer to the development and experience of using the ‘Watermatic’ sensor in recreational turf and horticultural applications.


