Horticulture Innovation Australia

Final Report

Application of soil amendments to maintain turf quality on sandy soild

Pieter Poot
The University of Western Australia

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Tel: (02) 8295 2300
Fax: (02) 8295 2399

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Summary

Background
The demand for water in our cities in southern Australia is expected to considerably increase in the next decade due to population growth and a warming climate. As a consequence, in a city such as Perth, substantial water deficits are predicted to develop as early as 2020. As a significant proportion of metropolitan water is used for turfgrass irrigation, turfgrass managers are facing future water restrictions, likely affecting turfgrass quality and growth. As there is increasing evidence that public greenspaces are important for maintaining people's physical as well as mental health and wellbeing, research into avenues of how to maintain turfgrass quality under limited irrigation is essential. Maintaining turfgrass quality under limited water supply is especially problematic in sandy soils which have a relatively low water retention and are thus highly dependent on frequent summer irrigation. Incorporating soil amendments consisting of finer particles into these sandy soils would likely reduce deep water drainage and would potentially lead to a more efficient use of irrigation water. Although there is a perception that adding amendments to the topsoil will reduce turfgrass water use, this has not been independently tested.

Objectives:

- test a range of locally available soil amendments (bentonite, kaolinite, spongelite, ReadyGrit™, zeolite, compost) for their efficacy in reducing turfgrass irrigation dependence, when incorporated into the top 100 mm of sandy soil
- identify the mechanisms responsible for variation in efficacy
- estimate the potential water savings

Target audience
Our target audience included a variety of sectors within the Turf Industry, including turf producers, local government, managers of parks and gardens, turf consultants, but also water supply organisations, environmental regulators, amendment suppliers, government policy makers and members of the general public.

Methods and Outputs
The project was carried out at the University of Western Australia's (UWA) Turf Research Facility in Perth, Western Australia. The effects of amendment incorporation on soft leaf buffalo turfgrass quality and growth was determined in a two-year field experiment consisting of 96 plots. Amendments were either incorporated in the topsoil individually or in combination with compost and were irrigated either two or three times a week. Research findings and recommendations were communicated to the Turfgrass Industry via field days, industry magazine articles and presentations at industry workshops and conferences.

Outcomes
Incorporating finer grained amendments (i.e. bentonite and kaolinite clays and compost) clearly increased topsoil water holding capacity and reduced deep drainage when compared to control plots or plots with coarser grained amendments. However, also in control plots none of the irrigation water drained beyond the root zone. In addition, plots with finer grained amendments, by retaining most water in the topsoil appeared more likely to lose irrigation water through soil evaporation. Therefore, under both irrigation rates, turf in plots with topsoil incorporated amendments did not differ in colour from turf in control plots.

In contrast, a subsequent soil column experiment showed that placing amendments (bentonite or compost) in a band lower in the soil profile (i.e. 5-15 cm deep) did improve turfgrass colour under limiting irrigation. Subsequent hydrological modelling indicated that placing finer grained amendments deeper (i.e. >3cm below the soil surface) can further reduce the loss of irrigation water to soil evaporation.

Recommendations and future research

To reduce irrigation water use in turfgrass, we recommend to incorporate fine grained amendments (clays, compost) at a rate of 5 or 10% (wt/wt), in a band of at least 10 cm and placed >3 cm below the soil surface. Only in situations with increased chance of irrigation water drainage (e.g. watering with large volumes, or watering turfgrass with shallow roots) is it likely that incorporation of amendments in the topsoil would be beneficial for turfgrass water use efficiency. Future research will have to validate the effects of deep banding on turfgrass water use efficiency in a field situation and establish optimal amendment type, placement depth and incorporation rates.

Keywords

amendments; irrigation requirements; kikuyu; root distribution; soft leaf buffalo; soil evapotranspiration; soil water content; turf growth; turf surface temperatures; water use efficiency

Introduction

Human population growth and a warming climate are likely to increase the demand for water worldwide leading to potential water shortages. This problem is exacerbated in regions that are likely to experience future rainfall reductions such as in the Mediterranean climate regions of Southern Australia. As a consequence, in a city such as Perth (Western Australia), substantial water deficits are predicted to develop as early as 2020 (Department of Water, 2010). A significant proportion of Perth's annual water use of 562 GL is associated with turfgrass irrigation, with over 10% used in community parks and gardens alone (Thomas, 2008). Additionally, more than 40% of household scheme water is used for watering home gardens including turfgrass, despite 32% of properties accessing private bore water (Water Corporation, 2010). Water restrictions have been introduced for scheme as well as private bore water over the last decade, in response to the increasing water demands and environmental concerns related to groundwater over-extraction. Considering the above, it is highly likely that turfgrass managers in Southern Australia (including home owners) will face additional water restrictions in the near future, affecting turfgrass quality and growth. As there is increasing evidence that public greenspaces are important for maintaining people's physical as well as mental health and wellbeing (Townsend & Weerasuriya, 2010), research into avenues of how to maintain turfgrass quality under limited irrigation is essential.

Maintaining turfgrass quality under limited water supply is especially problematic in sandy soils (e.g. Western Australia's coastal plain, 'sandbelts' of Melbourne, southeastern suburbs of Sydney), which have a relatively low water retention and are thus highly dependent on frequent summer irrigation. Earlier research investigated the effect of different watering allocations on turfgrass quality and assessed the benefits of applying soil wetting agents (Barton & Colmer, 2011abc; Barton, 2015). They showed that a water allocation below 7500kL/ha per year, which is equivalent to replacing about 70% of Perth's net evaporation during the irrigation season, decreased turf grass colour and growth, particularly in dry summers. Soil wetting agents improved turfgrass colour at both 6250 and 7500kL/ha per year application rates, presumably by increasing water infiltration. However, even with increased infiltration, in a sandy soil a significant fraction of irrigation water may drain beyond the root zone. Incorporating soil amendments consisting of finer particles into these sandy soils, would likely reduce deep drainage and would potentially lead to a more efficient use of irrigation water. Indeed fly ash incorporation in the top 100 mm of a sandy soil allowed a reduction in turf irrigation (Pathan, 2004), however, due to health concerns this technology was not taken up.

Currently, several Australian companies promote products as soil amendments or conditioners that will improve 'plant' performance, and decrease water and nutrient use. Similarly, government agencies and water suppliers are advising households to be 'water wise' and utilise soil amendments. However, most of these products have not been rigorously evaluated in Australian turfgrass systems and thus their efficacy and their exact mode of action remain unclear.

The objectives of this study were to:

- test a range of soil amendments for their efficacy in reducing turfgrass irrigation dependence, when incorporated into the top 100 mm of sandy soil
- identify the mechanisms responsible for variation in efficacy
- estimate the potential water savings

Methodology

Research methodology

Study site

All experiments were carried out at the UWA Turf Research Facility at Shenton Park in Perth, Western Australia. Perth has a Mediterranean type climate with dry summers and mild moist winters, with a mean summer monthly maximum temperature of 31.7°C (February) and an annual rainfall of 728 mm, mostly falling from May to September (BOM, 1994-2016 data). The field station occurs on the Spearwood Dune System and the soil is locally known as Karrakatta Sand (McArthur and Bettenay, 1960). The facility provided the infrastructure necessary for field experimentation including a variable-speed travelling irrigator, that allowed water to be applied relatively evenly and at known rates, and a local weather station, which allowed the calculation of local evapotranspiration (ET).

In 2012 a tender was put up by the UWA Turf Industries Research Steering Committee to solicit potential amendment suppliers to participate in the research trial. Thereafter, a subcommittee was formed, consisting of a wide representation of Turf Industry stakeholders, who voted which amendments should be included in the research trial. Decisions were based on knowledge of amendment characteristics, their local availability and perceived economic viability, and the willingness of suppliers to financially contribute to the project. Five inorganic (bentonite, kaolinite, ReadyGrit^{TM}, spongelite, zeolite) and one organic amendment (mature compost) were included in the field trial. For further product information and suppliers see Table 1 and Appendix 1.

Amendment	Supplier	Main constituents	Texture
Bentonite	Watheroo Bentonite	Clay minerals	Fine
Compost	Amazon (Mature Fine Compost)	Composted organics and greenwaste (high in nutrients)	Intermediate (mixture of fine and larger particles; generally <16 mm)
Kaolinite	Soil Solver (without added silt & minerals)	Clay minerals	Fine
ReadyGrit^{TM}	GMA Garnet	Coarse textured sands (by product mining industry)	Intermediate
Spongelite	Stronach & Associates	Fossilized porous marine deposits	Coarse
Zeolite	Castle Mountains (FM 16/30)	Microporous alumino silicate minerals (produced through volcanic activity)	Intermediate (particle size 0.5-1.2 mm)

Table 1. *Specification of amendments used in the turf trial. Note that the texture column reflects the*

most abundant particle size in the materials used (also see Appendix 1).

Testing the effects of amendment incorporation: a field study during two irrigation seasons

During the first two irrigation seasons (i.e. summers of 2013/2014 and 2014/2015) the effects of amendment incorporation, in the top 100 mm of the soil, on turf quality and water use was tested in a large field experiment. The experiment was conducted on a 68 by 19 m level land area that was cleared of native vegetation (Banksia woodland) in 1996 and has been used for turf trials since. The experiment consisted of 96, 3.5 by 2.5 m plots that were laid out in 8 blocks of 12 plots (see Fig. 1). The 12 plots in each block had 6 plots with individual amendments, 5 plots with inorganic-organic amendment combinations and 1 plot without amendments (control) (see Table 2). Amendment incorporation rates were standardized at either 5% (bentonite, spongelite and zeolite) or 10% (compost, kaolinite and Readygrit™) and were based on rates nearest to suppliers' recommended rates. A 50 mm layer of topsoil was removed and discarded. Thereafter, plots were delineated and amendments were homogeneously spread across their respective plots and rotary hoed into the surface 100 mm of the remaining soil during mid-October 2013. One week later, turfgrass rolls were laid and plots were further levelled with a small pedestrian roller. The choice of turfgrass species, soft-leaf buffalograss (*Stenotaphrum secundatum*; variety: Palmetto), is based on industry recommendations and reflects the wide use of this species and variety for new or replacement turfgrass for amenity areas in many regions of Australia.

Single amendment treatments	**Application rate**	**Combined treatments**	**Application rate**
1. Control			
2. Bentonite	5%	8. Bentonite + Compost	5% + 10%
3. Kaolinite	10%	9. Kaolinite + Compost	10% + 10%
4. ReadyGrit™	10%	10. ReadyGrit™ + Compost	10% + 10%
5. Spongelite	5%	11. Spongelite + Compost	5% + 10%
6. Zeolite	5%	12. Zeolite + Compost	5% + 10%
7. Compost	10%		

Table 2. *Specification of treatments used in the field experiment. Note that application rates are expressed as the weight of the product as a percentage of soil dry weight in the top 100 mm of the soil.*

Each plot was equipped with a 1 m transparent 'Rhizotron access tube' (inserted at 45^0 angle), to allow photographic recording of the developing root systems, and a 1.6 m deep PVC access tube (Sentek Diviner) to allow regular soil moisture measurements at different depths. In addition, there were weekly or two-weekly measurements of turfgrass growth, colour (Chroma Meter) and leaf surface temperatures (Infrared Camera). Plots were either irrigated 3 times per week at 65% evapotranspiration (ET) replacement (high irrigation treatment: 4 blocks) or 2 times per week at 43% ET replacement (low irrigation treatment: 4 blocks). During the second irrigation season these values were slightly increased to 75% and 50%, respectively. The experimental treatments were started on February 3rd 2014, three months after the turfgrass was established. For an overview of turfgrass agronomic management (e.g. fertiliser and mowing regimes) and further measurement details see Appendix 1.

In the third irrigation season the field site was used to test the effects of topdressing on turf quality and water use, with half of the blocks being topdressed with 10 mm of sand. Apart from the usual purpose of topdressing (e.g. rejuvenation and reducing the built up of organic matter), we applied this treatment because hydrological modelling showed that it could potentially reduce the amount of water lost through soil evaporation. However, results indicated that there was a legacy of the two previous years of high and low irrigation treatments, effectively reducing the level of replication in this experiment to two plots per treatment combination. This did not allow for any reliable conclusions to be drawn and the results of this experiment have therefore not been included in the report.

Figure 1. *Overview of the field experiment evaluating the effect of 12 amendment treatments and 2 irrigation regimes on turfgrass quality and water use.*

Testing the effects of amendments incorporated at deeper soil levels: a soil column experiment

Hydrological modelling of water flows in sandy soils with and without incorporated amendments showed that incorporation of amendment bands deeper in the soil could potentially reduce the amount of water lost through soil evaporation. To test the potential benefit of placing amendment bands deeper in the soil, a large soil column experiment was setup. PVC columns (65 cm deep, 30 cm in diameter) were placed in a trench at the Shenton Park field site (see Fig. 2). Soil profiles in the columns were constructed to either reflect the onsite soil profile with 15 cm of grey sand on top of 45 cm of coarser grained yellow sand, or had yellow sand throughout. Bands of compost or bentonite were positioned either in the top 10 cm of the soil profile, identical to the field experiment, or at a depth of 5-15 cm, with some columns left as un-amended controls. Apart from soft leaf buffalo, we also included kikuyu in this experiment as well as soil columns without turf. All together the experiment consisted of 3 turfgrass 'species' treatments, 2 soil profiles, 5 banding treatments and 5 replicate columns per treatment combination, resulting in 150 soil columns. Circular pieces of turfgrass were cut and placed inside the soil columns in early November 2015. Experimental irrigation rates (hand watering) were imposed from mid-January 2016 and were increased from 50 to 60% ET replacement (hand watering) in early February 2016. Regular measurements included: turfgrass colour (Chroma Meter), growth (clippings collected with an adapted goat shearer and vacuum hose), surface temperature (Infrared Camera), column evapotranspiration (custom made dome with temperature and humidity sensor) and soil moisture (Sentek Diviner). Fertiliser and mowing regimes were kept as similar as possible to the field experiment.

Figure 2. *Overview of the soil column experiment to evaluate the effects of incorporating bentonite or compost in a band either at 0-10 or at 5-15 cm depth.*

Statistical analyses

To determine differences between amendment treatments and across soil depths in a range of variables, analyses were carried out in R using the base and the lme4 package (RStudio Team, 2015; Pinheiro et al. 2014). We followed the approach as advocated by Zuur et al. (2009). Mixed-effect models were formulated for each variable of interest (e.g. turf colour, soil volumetric water content, turf surface temperature etc.) including all possible main effects (e.g. amendment treatment, time, distance to site edge for each plot, block) and their interactions ('beyond optimal model'). Thereafter, the best variance structure for the models was determined by incorporating random factors. In all cases, best models incorporated the time dependence of subsequent measurements on plots or soil columns ('repeated measures') in the variance structure. Subsequently, models were simplified by removing fixed factor interactions and main effects and comparing models with and without them to evaluate their significance (at $P<0.05$). P values of the best remaining model for each variable were then used to determine specific significant differences between amendment treatments and the control. Note that in the large field experiment separate models were formulated for the low and high irrigation treatments. In the 'Outcome' section of the report, differences between treatments as described in the text refer to P values smaller than 0.05.

Technology transfer

Uptake of findings was deemed most likely by having an effective communication strategy which was overseen by the UWA Turf Industries Research Steering Committee. The strategy involved providing research end-users with regular updates both in oral and written form as well as with opportunities to visit the field site and observe treatment effects, and included the following:

- Dissemination of project progress and outcomes by committee members to their respective state and national associations
- Regular newsletters to industry partners (distributed nationally as well as available on our website)
- Annual field days at the UWA Turf Facility
- Presentation of research findings at local and national industry conferences, seminars and workshops
- Publication of research progress in national industry journals
- A final workshop for industry partners to summarise project outcomes and discuss results
- Distribution of progress and final reports to Hort Innovation and industry partners

Current UWA Turf Industries Research Steering Committee membership includes representation of: WA Turf Growers Association, Golf Course Superintendents Association of Western Australia, Water Corporation, Department of Water, WA Local Government, Lawn Mowing Contractors Association, Irrigation Association of Australia (WA Region), Sports Turf Association of Australia, WA Bowling Association, the fertiliser industry, private turfgrass consultants and UWA research staff.

Project evaluation

Throughout the duration of the project the UWA Turf Industries Research Steering Committee evaluated the aims and experimental approach. The project leader updated the committee regularly of the newest research findings. These were then discussed and potential changes to the existing experimental design or future planned experiments, as a result of these findings, were agreed upon. For example, the absence of clear beneficial effects of any of the amendments in the first two irrigation seasons, led to the topdressing and soil column experiment in the third season. The final workshop with industry partners (28 Nov 2016; 30 participants) summarised and informally evaluated the outcomes of the project. Most participants indicated that they regarded the project as highly valuable by independently showing that (1) incorporating amendments in the topsoil is not likely to improve turf quality and reduce water use, whereas (2) incorporating them deeper in the soil profile may have the desired effects.

Outputs

As outlined in the previous section a communication strategy, overseen by the UWA Turf Industries Research Steering Committee, was developed to ensure regular and wide dissemination of project outcomes and results. Although the UWA Turf Research staff was mainly responsible for disseminating research findings, we were assisted by committee members who communicated findings to their respective state and national associations on a regular basis (i.e. following each committee meeting). The activities undertaken to facilitate adoption of our research findings are presented below, with those delivering final outcomes to our target audience marked with an asterisk.

Field days

To provide an opportunity to people in the turf industry to view experiments and observe and evaluate the effects of different treatments, field days were organized annually in mid-summer. Field days were advertised widely and attracted a variety of people and organisations with interest in turf, including: turfgrass managers (e.g. local government, golf courses, schools), turfgrass producers, businesses that service the turfgrass industry, water supply organisations, environmental regulators and government policy makers. At the start of these days, the project leader would provide an overview of the results obtained after which attendants could move around freely on site and discuss results in smaller groups. Field days were held on the following dates:

- 19 Feb 2014, attendance: ~ 160
- 18 Feb 2015, attendance: ~ 105
- 17 Feb 2016, attendance: ~ 70

Note that the first two field days were shared between two Hort Innovation funded projects, and thus that the lower attendance on the last field day is not likely to be due to decreased interest. Informal feedback provided at the end of field days invariably indicated that people were highly appreciative of these opportunities to observe the effects of treatments and discuss them with us.

Industry conferences, seminars and workshops

Research findings were presented locally to the Turfgrass Industry, including turfgrass managers, turfgrass producers and staff from a variety of organisations liaising with the Turfgrass Industry:

- Poot P. 2013. Application of soil amendments to maintain turf quality on sandy soils under reduced irrigation. 2013 WA Turf Seminar Day, Alfred Cove (Western Australia), 17 July.
- Poot P & Azam G. 2015. Application of soil amendments to maintain turf quality on sandy soils under reduced irrigation. 2015 WA Turf Seminar Day, Alfred Cove (Western Australia), 29 July.
- Azam G & Poot P. 2015. Application of soil amendments to reduce irrigation demand by turfgrass. Water Wise Councils Forum, Leederville, 21 October.
- Poot P & Azam G. 2016. Turf soil amendment project final workshop. The University Club, Crawley (Western Australia), 28 November.

Newsletters

The turf industry and wider community were kept up to date with the project's progress via the UWA Turf Research Program Newsletters (distributed every ~3 months). A total of 11 newsletters were produced during the project. Newsletters were distributed electronically in pdf format and were also made available from the UWA Turf Research Program website (http://www.plants.uwa.edu.au/research/turf-research-program). In addition, project updates and findings were presented in Association Newsletters via members of the UWA Turf Industries Research Steering Committee. Association newsletters included 'Turfgrass Times' (Sports Turf Association WA and WA Turf Growers) and 'Overflow' (Irrigation Australia Ltd. WA).

Publications in industry journals

Nationally, people in the turf industry were kept up to date with project progress via regular publications in the turfgrass journals:

- Poot P, Azam G, Barton L & Colmer T. 2014. Water savers. Australian Turfgrass Management Journal, Volume 16.3, pp. 74-76.
- Azam G & Poot P. 2015. Water savings with soil amendments. Australian Turfgrass Management Journal, Volume 17.3, pp. 52-54.
- Poot P & Azam G. 2016. Do amendments reduce water use? Australian Turfgrass Management Journal, Volume 18.3, pp. 58-60.
- Poot P & Azam G. 2016. Do soil amendments reduce turf water use. Turf Australia, Winter 2016, pp. 26-28.

Scientific conferences

Results of the project were discussed at two scientific conferences:

- Azam G & Poot P. 2015. Infiltration and retention of water by amended sandy soil. WA Soils Conference, Mandurah, Western Australia, 7-9 September.
- Azam G & Poot P. 2015. Effects of amending sandy soils on distribution of roots and colour of turfgrass under two irrigation regimes. International Society for Root Research congress, Canberra, 6-9 October.

Outcomes

The main outcome of the project is the demonstration that incorporating amendments in the top 10 cm of a sandy soil in a seasonally dry Mediterranean climate does not lead to a more efficient use of irrigation water by turfgrass and thus does not result in any water savings. Although especially the finer grained amendments (i.e. clays and compost) clearly increased the water holding capacity of the top soil and prevented deep drainage, also in control plots none of the irrigation water actually drained beyond the root zone. In contrast, incorporating amendments deeper in the soil profile, did ameliorate turfgrass colour and is likely to result in water savings. These findings are highly relevant for the Turfgrass Industry as they should prevent potential further uptake of a non-profitable practice (i.e. incorporating amendments in the topsoil to save water), while at the same time providing an alternative avenue that is more likely to be successful (i.e. incorporating amendments into deeper soil layers). These findings may also be relevant for the broader horticultural industry and for society as a whole, as a more sustainable use of water is an important component of our adaptation to a warming and drying climate.

Results: amendment incorporation in the topsoil

During irrigation seasons the large field experiment did not show clear and consistent effects of any of the amendment treatments on turfgrass colour, when compared to control plots (Fig. 3). After onset of the experimental treatments, turfgrass colour quickly deteriorated in the low irrigation treatments in both years and plots developed desiccated brown patches (Fig. 4). Only in the first irrigation season, some of the amendment treatments (i.e. notably kaolinite, compost + spongelite, compost + Readygrit™) initially slightly delayed turfgrass browning, but no such effect was observed during the second irrigation season. In contrast, the high irrigation plots only showed a slight deterioration in colour without clear amendment effects, although compost amended treatments tended to be slightly greener especially during the second irrigation season. A similar effect was seen during the winter season with compost amended treatments remaining greener than plots in other treatments. This is likely to be a response to the higher nutrient availability in these plots as compost is well known to be rich in nutrients.

Amendments containing finer particles (i.e. bentonite, kaolinite and compost) clearly increased the topsoil water holding capacity and resulted in higher topsoil volumetric water contents at all times during weekly irrigation cycles (Fig. 5, top panels). However, these fine particles also increased the fraction of water that is tightly bound and is not available for plant uptake. Thus, the apparently higher topsoil water contents of many amended plots at the end of an irrigation cycle are deceptive as they do not reflect an increased water availability. Indeed, the development of desiccated brown patches in the low irrigation plots was closely associated with soil water contents dropping below the wilting points for each respective amendment treatment (e.g. ~3% for the controls and 3-6% for amendment treatments).

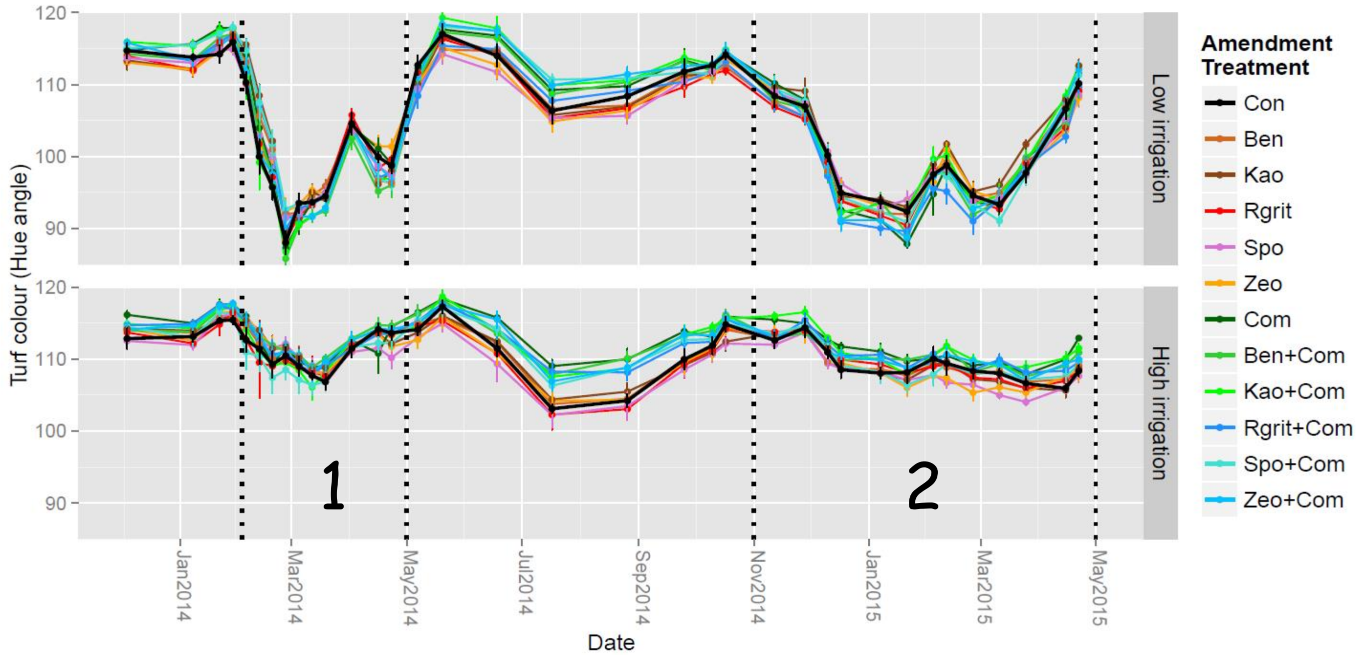

Figure 3. *Time course of turfgrass colour ('Hue value') as dependent on level of irrigation and amendment treatment. Numbers indicate the first and second irrigation season, with dotted lines marking the start and end of these seasons. Note that 'Hue values' below 100 were associated with clear loss of colour and development of brown and desiccated patches within plots, whereas values above 110 were indicative of unstressed healthy looking plots (for further reference see images in Figure 4). The low irrigation plots were watered twice per week (43-50% ET replacement), whereas the high irrigation plots received watering three times per week (65-75% ET replacement). Amendment treatments: Con= Control, Ben=Bentonite, Kao=Kaolinite, Rgrit=ReadyGrit™, Spo=Spongelite, Zeo=Zeolite, Com=Compost.*

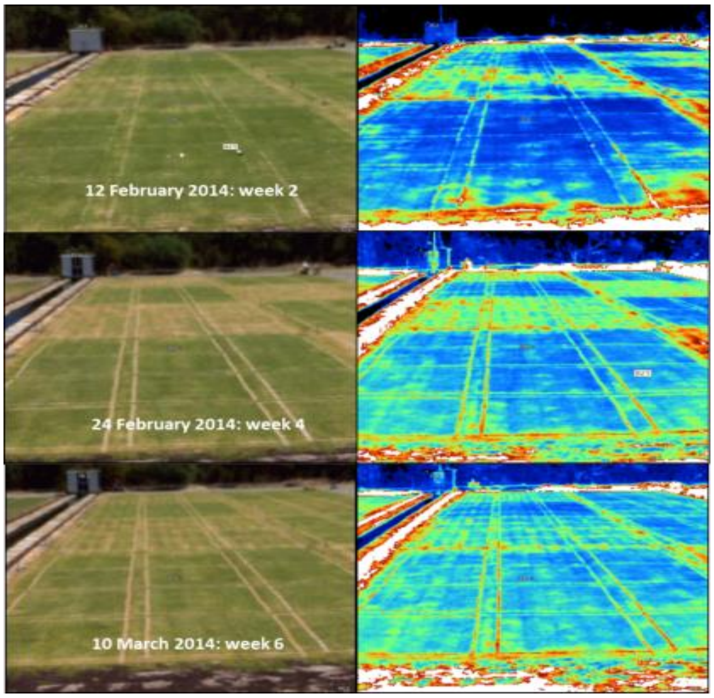

Figure 4. *Simultaneous colour and infrared images of the amendment turf trial at the UWA Turf Research Facility during the first irrigation season. Week numbers indicate weeks since the start of the experimental irrigation treatments. Blue colours indicate lower surface temperatures whereas yellow, red and white represent increasingly warmer temperatures.*

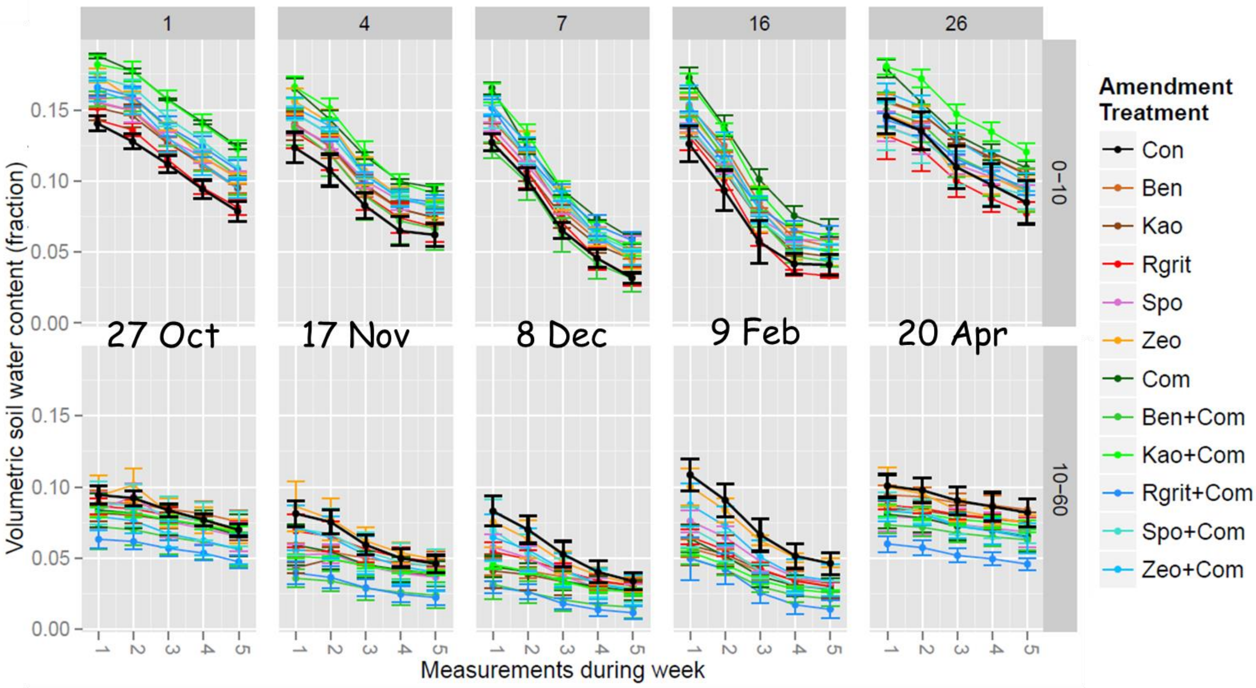

Figure 5. *Weekly decline in soil volumetric water content in the low irrigation treatment at 0-10 cm depth (i.e. in the amendment band, top panels), or 10-60 cm depth (below the band, bottom panels), during the second irrigation season. Plots were irrigated early Monday morning and were not watered again until early Friday morning. Note that the first two points in each panel are morning and afternoon measurements on day 1, whereas the last three points represent measurements on day 2, 3 and 4. The numbers at the top of the figure represent weeks since start of the irrigation season.*

As intended, most finer-grained amendments greatly reduced drainage of irrigation water to deeper soil layers when compared to control plots (Fig. 5, bottom panels). However, crucially, even in control plots none of the water drained beyond the root zone, as roots were observed to depths of at least 70 cm, whereas irrigation water did not drain further than approximately 50 cm. This does not necessarily mean that control plots can extract all irrigation water from deeper layers, as root densities decrease strongly with depth and some water may still be out of reach. However, amended plots retain most water in the topsoil and are likely to be more susceptible to irrigation water loss through soil evaporation. In addition, the high water contents in the topsoil of amended plots may stimulate turfgrass growth and evaporative water loss in the first two days after irrigation. As no clear differences in turf quality between treatments were observed it is likely that the above processes have cancelled each other out. The slight positive effects of some amendments 3 months after turfgrass establishment may also be explained by these mechanisms: most roots would still be in the topsoil and overall root densities would have been much lower at this early stage which would have resulted in more drainage and thus larger irrigation water losses in control plots.

As the field experiment conducted over two consecutive summers did not show any clear advantages of incorporating amendments in the topsoil, the third objective of the study to ‘estimate the potential water savings’, was not relevant. Instead, a soil column experiment was conducted to establish whether placing amendments in a band deeper in the soil profile would be more effective than placing them in the surface soil.

Results: amendment incorporation in deeper soil layers

The results of the soil column experiment further validated those of the field experiment for compost and bentonite and showed that results were largely independent of sand type (i.e. soil profile) and turfgrass species. Similar to the field experiment turf colour quickly deteriorated after onset of the treatments and only slowly started to recover after an increase in irrigation rates from 50 to 60% ET replacement in early February (Fig. 6). Treatments with the amendments (bentonite or compost) incorporated in the topsoil had a similar or marginally better colour than those of control plots. However, independent of soil profile or turfgrass species, treatments with amendments incorporated deeper in the soil (i.e. 5-15 cm depth), were invariably greener than those from the other treatments (Figs. 6 & 7). They also tended to evaporate more water and had cooler surface temperatures, both observations suggesting a better water supply. Independent hydrological modelling of these soil profiles (without turf) also showed that deeper amendment bands can reduce soil evaporation by maximally 20% when compared to non-amended controls. The modelling suggested that a top layer of sand of at least 3 cm would allow irrigation water to infiltrate fast thereby reducing initial evaporative losses associated with slow infiltration. Once in the amendment layer the water would be more tightly bound and less likely to escape back to the atmosphere, reducing overall evaporative losses.

Figure 6. *Time course of turfgrass colour ('Hue value') as dependent on turf species, sand profile and amendment treatment, during the summer of 2016 in the soil column experiment. Amendments were either placed at 0-10 or at 5-15 cm depth.*

Impacts for turf industry

The main assets of this project for the turf industry are that the project (1) has provided independent evidence on a wide range of amendments demonstrating that topsoil incorporation is not likely to improve turf water use efficiency on sandy soils, (2) has greatly enhanced our understanding of the mechanisms involved, and (3) has provided alternative options that are more likely to be successful. Thus, the project has greatly increased turfgrass managers' understanding of the opportunities and constraints of using amendments to increase turfgrass water use efficiency. This will ultimately assist in maintaining our green spaces, benefiting our physical and mental wellbeing, and will enhance our capability to adapt to a warming and drying climate.

Figure 7. *Example of differential turfgrass desiccation during severe drought stress in February 2016 in the soil column experiment (right), and a soil column at the final harvest with compost incorporated in a band at 5-15 cm depth (left).*

Evaluation and Discussion

During all stages of this project members of the UWA Turf Industries Research Steering Committee have been actively involved in decision making, including (in chronological order):

- determining the process used to identify which amendment products should be included in the trials
- formulating the main aim of the trials
- ensuring an adequate initial experimental setup that could deliver the formulated outcomes (e.g. making decisions on depth of amendment incorporation, incorporation rates and the use of inorganic-organic mixtures)
- deciding how to change the experimental approach after the field experiment failed to show beneficial effects of amendment incorporation

The strong involvement of the Steering Committee, which has stakeholders in all facets of the local turf industry including end-users, has ensured that the project has been effective throughout its duration and has delivered relevant outcomes to the Turf Industry.

Annual field days provided research end-users with up to date information on the results of the trials, and the opportunity to view the effects of the treatments themselves and discuss these with project staff and other people in the turf industry. Interest in, and success of the project was also reflected by the large attendance during these days (varying from 70 to over 150; see Fig. 8) and the invariably positive correspondence received following the events. Key industry conferences and publications further extended project outcomes to the wider Turfgrass Industry (see 'Outputs' section).

The original objectives of this project were to (1) independently test a range of locally available soil amendments for their efficacy in reducing turfgrass irrigation dependence, when incorporated into the top 100 mm of sandy soil, (2) identifying the mechanisms responsible for variation in efficacy and (3) to estimate the potential water savings. These objectives illustrate the confidence of Committee members and the Turf Industry at the start of the project, that incorporation of at least some of the amendments would lead to a more efficient use of irrigation water. This confidence appears to have been mainly based on the conviction that irrigation water drains quickly in sandy soils and thus that a substantial part of the irrigation water may be lost to deep drainage beyond the root zone. However, soil moisture measurements combined with root observations (i.e. rhizotron tubes and excavations) have clearly shown that the irrigation water did not move beyond the rooting zone. Although, as outlined in the 'Outcomes' section this does not prove that all irrigation water provided has been taken up, it makes it very unlikely that the amount of water lost is substantial. In addition, the slower infiltration of irrigation water in amended soils and its restriction to the warmest part of the soil closest to the atmosphere, has made it more susceptible to direct evaporation. Also, the presence of high water contents in the topsoil of amended plots, where most of the turfgrass roots are situated, is likely to have stimulated leaf growth in the day following irrigation, thereby further increasing turfgrass water use.

Although the results of the large field experiment were unexpected, and invalidated the third objective of this study (to determine the water savings of adding amendments to the top soil), the detailed measurements taken allowed us to understand the underlying mechanisms better and enabled us to provide a logical explanation to stakeholders. The mechanisms involved make it unlikely that incorporation of amendments at different rates, applying different amendments all together, or repeating the experiment with different turfgrass species or on different types of sandy profiles, would have led to fundamentally different results. Indeed, the soil columns experiment showed that for compost and bentonite results were virtually similar for 2 turfgrass species and on 2 substantially different sandy profiles. In contrast, Pathan et al. (2004) showed that turfgrass plots with topsoil incorporated fly ash (5/10/20% wt/wt) did retain colour when irrigated at 40% evaporation replacement rate. However, their measurements were based on pan evaporation which is substantially higher than evapotranspiration, and therefore their irrigation volumes were closer to our 'high irrigation' treatment. In addition, in their experiments plots were watered every third day and the experiments were conducted with a different turfgrass species (*Cynodon dactylon*). Also, their one year old plots were de-thatched 49 days prior to the start of irrigation treatments. This process would have increased water infiltration rates, potentially resulting in a larger loss of irrigation water through drainage especially in control plots. Overall there seems little evidence that amendment incorporation in the topsoil would lead to substantial water savings. However, in situations where deeper water infiltration beyond the root zone is more likely, such as (1) in recently established turfgrass with relatively shallow roots, (2) in more shallow rooted turfgrass species, (3) after de-thatching or other renovation techniques that may affect infiltration, or (4) in turfgrass systems with more frequent and higher volume irrigation, amendment incorporation may still be profitable. Amongst potential amendments to be used, it seems clear that those with a high percentage of finer sized particles (clays and compost) would be more likely to result in positive effects.

Figure 8. *Selection of pictures of field days at the UWA Turf Research Facility, on which Industry Members and other stakeholders were given the opportunity to visit the soil amendment field plots and discuss the project outcomes.*

The results of the soil column experiment and the independent hydrological modelling both suggest that applying amendments in a band deeper in the soil profile is much more likely to reduce irrigation water losses through soil evaporation, and have a positive effect on turfgrass quality. These results are very promising but would need further validation in both field experiments and in hydrological modelling, to assess the effects of different types of amendments and to determine optimal placement depth and incorporation rates. This would also allow the determination of potential water savings, which would be essential to convince the Turf Industry, their end-users and water regulators to promote and use the technology. If proven successful, the technology could also be used to reduce water use in the broader Horticultural Industry. The UWA Turf Industries Research Steering Committee has prioritized further research into amendment technology and its potential water savings as one of two projects to further develop and seek funding for.

Recommendations

Both recommendations below pertain to turfgrass grown in seasonally dry environments (e.g. Mediterranean climates) on sandy soils and concern the effects of amendments on turfgrass water use efficiency. Potential positive effects of amendment incorporation on nutrient leaching were not specifically investigated in the current research project.

Amendment incorporation in the top soil

In general we do not recommend amendment incorporation in the topsoil.

However, amendments in the topsoil could positively affect turfgrass water use efficiency in situations where deep water infiltration beyond the root zone is more likely, such as:

(1) in recently established turfgrass with shallow young roots
(2) in more shallow rooted turfgrass species
(3) after de-thatching or other renovation techniques that increase water infiltration
(4) in turfgrass systems with more frequent and higher volume irrigation

In the above situations, amendments with a higher proportion of fine-textured materials such as clays (e.g. kaolinite, bentonite) and compost would be more likely to be beneficial, with incorporation rates set at 5% or higher (wt/wt).

Amendment incorporation in a band deeper in the soil profile

We recommend amendment incorporation in a band below the soil surface.

Our initial modelling, based on a band with bentonite and compost combined, suggests that this band needs to be at least 3 cm below the soil surface, with the largest effects on reducing soil evaporation observed with a band of at least 10 cm width, positioned between 6 and 16 cm depth. Further modelling and experimentation will have to be conducted to confirm these findings.

Volume and frequency of watering turfgrass in a Mediterranean climate

Although this project did not specifically investigate volumes and frequency of watering to maintain turf quality, results suggest that watering 2x per week (according to current water restrictions) at 40% ET replacement is not sufficient to maintain turf colour. Results of the soil column experiment suggest that to retain turfgrass colour, watering rates of at least 60% ET replacement should be in place.

Scientific Refereed Publications

None to report.

IP/Commercialisation

No commercial IP generated.

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Appendices

Appendix 1: Amendment products

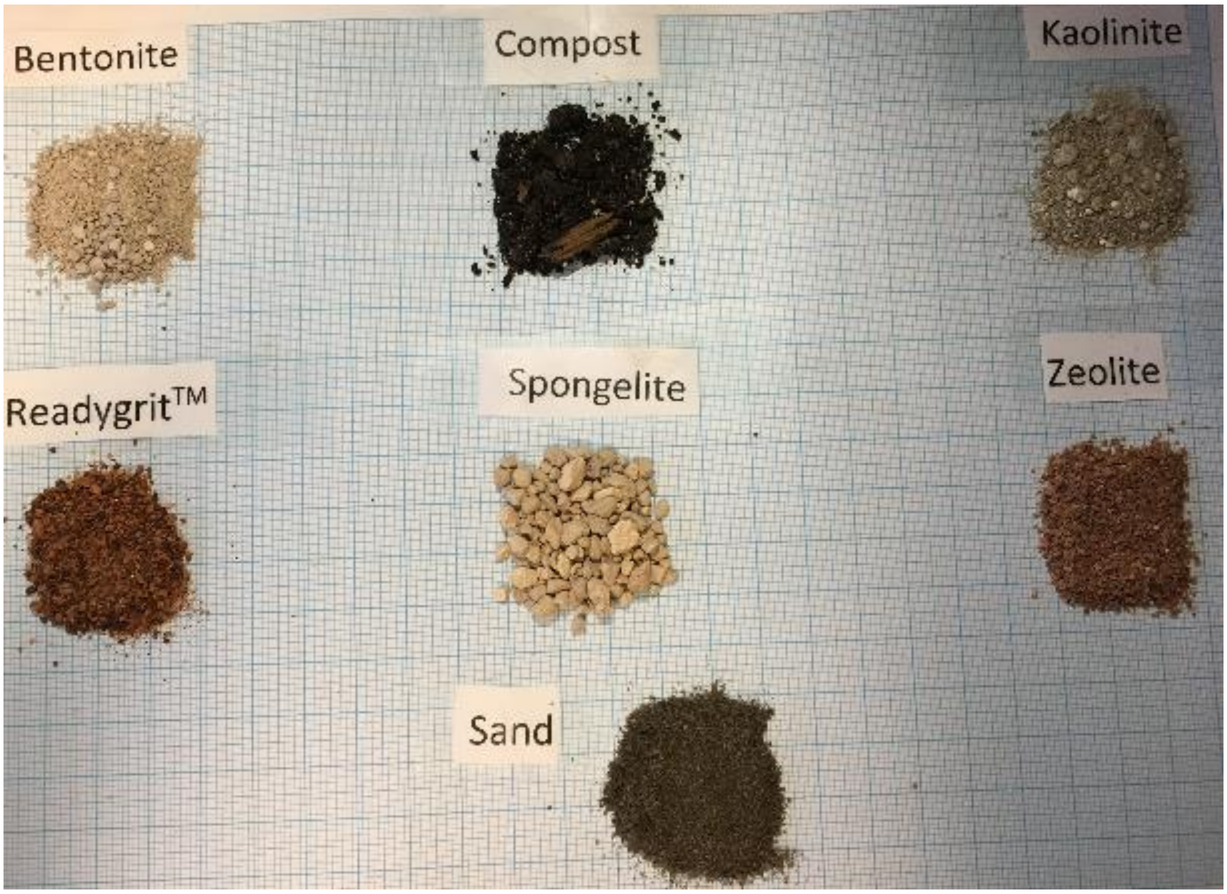

Figure 1. *Visualization of applied amendments compared to field site surface sand (top 100 mm).*

Appendix 2: Supplementary methodology

Study site

Agronomic techniques used in the large field experiment (e.g. fertilizer and mowing regimes) were based on local industry practice and were determined after consultation with the UWA Turf Industries Research Steering Committee (Appendix 1, Table 1). For the soil column experiment similar techniques were used but mowing was done with a custom-made 'mower', consisting of a goat shearer with attached vacuum hoses.

Appendix 1. Table 1. Summary of turfgrass management

	Frequency	Other details
Mowing	Weekly from spring to autumn otherwise fortnightly	Cylinder mower, cutting height of ~20 mm
Fertiliser	Four times a year (2 in spring, 2 in autumn)	Baileys 3.1.1. fertilizer, 234 kg/ha per application (i.e. 37.5 kg N/ha)
Soil wetting agent	Used in topdressing experiment only (not detailed in this report)	

Measurements

Below, more detailed information on the measurements taken in both the field and soil column experiments is provided. Note that not all measurements could be referred to in the main report. Further information on these can be acquired by contacting the author of the report. In addition, several manuscripts are currently being prepared for scientific publications; these also will include results that have not been incorporated into this report.

Turfgrass growth of each plot (8.75 m^2) or soil column (0.07m^2) was determined by weighing the dry mass of clippings. During the experimental irrigation periods, plots and columns were mown weekly at a height of ~20 mm and fresh mass of clippings was collected and weighed. Dry mass was determined on subsamples which were dried in an oven (60°) for at least 48 hours. The remaining fresh clippings were not returned to the plots.

Turfgrass colour was measured once a week or fortnight with a Chroma Meter (model CR-410, Konika Minolta), which enables quantification of turfgrass colour (Landschoot & Macino, 2000; Barton et al., 2006). For each plot 10 random measurements were taken, whereas for each soil column 5 random measurements were taken, by pressing the measuring cylinder (50 mm in diameter) of the Chroma Meter onto the canopy surface to exclude external light.

Turfgrass surface temperatures were measured regularly with an infrared camera (TiR-32 Thermal Imager, Fluke Thermography) on sunny days only. Separate images were taken for each plot and for 4 adjacent soil columns. To calibrate the temperatures in each image a custom-made aluminium plate (5 x 5 cm) with an attached thermocouple (type K, 0.1 s response time), was positioned inside each image. The surface temperature of the aluminium plate, as indicated by the image software (SmartView 3.14), was compared to its real temperature, and the offset was then used to correct the average temperature of all turfgrass pixels inside each plot or soil column.

Soil volumetric water content inside each plot or soil column was measured with a 1.5 or 1m capacitance moisture probe (Sentek Diviner 2000, Sentek Sensor Technologies), which records average volumetric soil water content every 10 cm. A PVC access tube was positioned inside each plot or soil column during the setup of the experiments. Holes of appropriate depth and diameter were dug using a vacuum hose system attached to a custom-made and sharpened stainless steel cylinder. Daily measurements were taken every fortnight to be able to record moisture drawdown within one irrigation cycle. Separate calibrations were done for each treatment to ensure reliable soil volumetric water content readings.

In the field experiment, 1 m long transparent acrylic rhizotron tubes were inserted at an angle of ~45° in the center of each plot. Holes were dug with a sharpened stainless steel cylinder attached to a vacuum hose. A custom made stainless steel guiding slide set at an angle of 45° was used while vacuuming to ensure consistent positioning of the rhizotron tubes. A CI-600 In-Situ Root Imager (CID Bio-Science) was used to capture 360° root images along the length of the access tube. Images were taken bi-annually and scored for the number of roots hitting the acrylic tube at each depth (i.e. roots preferentially growing along the tube were only counted once). At the end of the field experiment 1 root core of 75 mm diameter was taken from each plot to determine root fresh mass and dry mass (after 48h of oven drying at 60°C) for every 10 cm depth up to 1 m.

In the soil column experiment, soil columns (PVC cylinders of 65 cm height, 30 cm diameter, with a lid glued to the bottom) were positioned in a trench at the far end of the field experimental plots. The depth of the trench was chosen to ensure that the surface of the circular turfgrass patches inside the columns was level with the surface of the turfgrass in the adjacent field experiment. All soil layers in each column were constructed by weighing each component (i.e. grey topsoil sand, yellow deeper sand, compost, bentonite) separately, based on earlier determined bulk densities and on the incorporation rates used in the field experiment, and mixing sand/amendment combinations thoroughly in a cement mixer. To ensure correct bulk densities, lines were drawn on the inside of each column for each change within the profile, and soil components were compacted to this line with a custom made wooden 'stamper'. Circular patches of turf were cut with a custom-made circular piece of sharpened stainless steel with a handle, and placed on the constructed soil profiles in the columns. At the end of the experiment a grinder with a cutting wheel was used to cut the PVC cylinders in half. A sharpened, circular piece of stainless steel with a handle was used to separate 5 cm bands in the top 15 cm of the profile, and 15 cm bands in the bottom 45 cm. Roots were washed out on sieves and fresh mass and dry mass (after 48h of oven drying at 60°C) for each layers was determined.

Other analysis that have not been detailed in this report include: chemical and physical analysis of pure amendment products as well as mixtures with sand, soil moisture release curves of soils under a range of amendment incorporation rates, soil nutrient concentrations in the column experiment, and leaf nutrient concentrations before the onset of experimental treatments in all experiments.