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QUALITY TURF AND EFFICIENT UTILIZATION OF RESOURCES

# Evaluation of the effects of incorporation rate and depth of water-retentive amendment materials in sports turf constructions

STANISLAV HEJDUK[1], STEPHEN W. BAKER[2] & CHRISTIAN A. SPRING[2]

[1]*Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic,* [2]*Sports Turf Research Institute, St. Ives Estate Bingley, West Yorkshire, BD16 1AU, UK*

**Abstract**

The objective of the current laboratory study was to assess the effects of a number of amendment materials and the depth of incorporation on water retention. 300 mm rootzone profiles were established in 150 mm diameter plastic cylinders over a 50 mm gravel drainage layer. Five amendment materials (sphagnum peat, compost, zeolite, TerraCottem and Stockosorb) were mixed with a medium-coarse sand at various rates. The upper rootzone layer (0–150 mm) included 50%, 100% and 150% of published or manufacturersã recommended rates of each amendment material. Three amendment rates were included in the lower rootzone layer (150–300 mm): pure sand, half the amendment rate of the top layer, and the same amendment rate as the top layer. The following measurements were made: water retention in individual layers, volumetric water content in the top layer (0–60 mm), shear strength, surface hardness, permanent wilting point. Water retention was significantly influenced by the different amendment materials. The most water retentive mixes were those containing peat and Stockosorb, whilst the least retentive contained the TerraCottem and the pure sand. The influence of amendment rate in the lower layer was less in comparison with the top layer. The incorporation of amendment materials in the lower rootzone had no significant effect on water retention in the upper rootzone but did increase the total water storage in the profile and this would have some implications for plant growth during drier periods.

Rootzone mixes containing peat and compost had the highest shear strength whilst the Stockosorb gave the lowest strength because the expansion of the polymer reduced rootzone density and therefore the degree of contact between the sand particles. The hardest surface was measured when zeolite was used and the softest surfaces resulted from the use of Stockosorb.

**Keywords:** *Amendment materials, compost, peat, rootzone, superabsorbent, turfgrass, water retention, zeolite.*

## Introduction

Sand-dominated rootzones are widely used for high-quality sports facilities because of their good drainage properties, greater air-filled pore space after compaction and more consistent playing characteristics, particularly in respect to the hardness of the surface (Adams 1986, 2008, Baker 1989).

Two of the potential problems associated with sand-dominated media are ensuring adequate water and nutrient retention. Accordingly, amendment materials are regularly added to the sand material and there has been a considerable amount of research on the effect of different amendment materials and application rates for sports turf rootzones (eg. Waddington et al. 1974, Cook and Baker 1998, Baker et al. 1999, 2010).

There has, however, been relatively little research work on the effects of the depth of the amended layer on water-retention properties of rootzones. There is a need to assess whether it is better for the amendment material to be applied through the entire layer of sand-dominated rootzone or concentrated in the surface layers where most of the root system is found. If there is no benefit of amending the lower rootzone, in terms of water retention, there may be significant cost benefits in only incorporating amendment material in the upper rootzone. The cost of a rootzone material is significantly greater when compared with sand and therefore if amending just the upper profile there would be a substantial saving in the cost of materials. Additionally, there is a logical argument to say that it would be desirable to

Correspondence: Stanislav Hejduk, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic. E-mail: hejduk@mendelu.cz

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have optimal water retention extending through the depth of the main rooting mass. The objective of the current study was to assess the effects of a number of amendment materials and the depth of incorporation on water retention within typical profiles used for sports turf construction.

## Materials and methods

The study was carried out under laboratory conditions using 150 mm diameter plastic cylinders. Within each column, a profile was constructed with a 300 mm rootzone layer over a 50 mm gravel drainage layer. The rootzone was based on uniform medium–coarse sand (Table I) and the base layer was a fine gravel of 2–5 mm size range. The sand and gravel coincided with the normal ranges for golf green construction (Baker 2006, STRI 2006) and, although the sand used in this experiment was slightly coarser than would be typically used for a football pitch, the data would be applicable to football as the needs of the grass plants are similar (Baker et al. 1999).

### *Experimental design*

A randomized block design was used with three main treatment groups: profile characteristics, amendment type and amendment rate. Pure sand rootzone was included as an experimental control, with two replicates in each block.

a. There were three profile configurations based on the rate of amendment material incorporation in the upper (0–150 mm) and lower (150–300 mm) part of the profile. The upper part of each profile was amended with a particular material at the given rate. The lower profile had three configurations where the same amendment material was incorporated at (i) the same rate as the upper profile, (ii) half the rate of the upper profile and (iii) no amendment in the lower profile (sand only).

Table I. Particle size distribution of the sand used in the experiment.

| Category | Particle diameter (mm) | % |
|---|---|---|
| Coarse gravel | 3.4–8.0 | 0.0 |
| Fine gravel | 2.0–3.4 | 0.2 |
| Very coarse sand | 1.0–2.0 | 2.1 |
| Coarse sand | 0.5–1.0 | 52.2 |
| Medium sand | 0.25–0.5 | 41.4 |
| Fine sand | 0.15–0.25 | 2.9 |
| Very fine sand | 0.053–0.15 | 0.4 |
| Silt + clay | Less than 0.053 | 0.9 |

b. Five amendment materials were used as follows:
   - Sphagnum peat (commercially available material).
   - Composted green waste (Bathgate Silica Sand Ltd.).
   - Zeolite (Clinoptilolite, grade 0.5–1.0 mm, Zeocem Inc., Slovakia).
   - TerraCottem Turf® (mixture of hydroabsorbent polymers of acrylamide and acrylic acid, partially neutralized by potassium and ammonia salts (31%), humic acids (18.8%), fertilizers (8%) and zeolite (42%) [weight proportions], TerraCottem n.v. Belgium).
   - Stockosorb M® (cross-linked potassium polyarylate/polyacrylamide co-polymer, grade 0.8–2.0 mm; The Resource Management Group, Inc. Atlanta GA 30350).

The latter two amendment materials are classified as superabsorbents. The term superabsorbents can be defined as polymers that are able to absorb and retain extremely large amounts of water relative to their dry mass (Horie et al. 2004). Three rates were used for each material, nominally 0.5, 1.0 and 1.5 times a typical rate for each material based on either earlier research or the manufacturer's recommended rate at the start of the trial (www.terracottem.com; www.stockosorb.com). Rates of 10, 20 and 30% by volume were used for the two organic materials and the zeolite (Baker et al. 1999, Cook and Baker 1998, Petrovic et al. 1998, 2008). For the TerraCottem the recommended rate was 600 g $m^{-3}$ and for Stockosorb 1200 g $m^{-3}$. Since the commencement of the trial, the incorporation rate for the Stockosorb has been lowered by the manufacturer to 330–660 g $m^{-2}$ for turf establishment purposes (Annette zur Mühlen, personal communication, www.evonik.com), whilst a higher rate of 1500–3000 g $m^{-3}$ is recommended for horticultural usage. All combinations were included within three randomized blocks. There were 47 cylinders in each block (5 materials $\times$ 3 rates in upper rootzone layer $\times$ 3 rates in lower rootzone layer + 2 pure sand rootzones).

### *Preparation of the profiles*

Each column was 375 mm high and had a voile membrane attached at the base and was supported on a perforated plastic mat to allow free drainage and ease of handling. A 50 mm layer of drainage gravel was added to the base of the column and then the lower rootzone (including any amendment as appropriate) was added in two layers, each of 75 mm thickness. Each layer was consolidated using four blows of a 2.82 kg weight dropped from a height of

0.39 m (packing energy for each layer = 2.5 kg $m^{-2}$). After each compaction treatment, the upper 5 mm was lightly raked to prevent layering and any adjustments to the height of the layer were made to give the desired 150 mm depth. The upper rootzone was then added, again in two layers, with the same compaction treatments to give a total depth of the rootzone of $300 \pm 10$ mm. The surface of the rootzone was 25 mm from the top of the cylinder allowing space for water to be ponded in the cylinder as part of the wetting procedure.

The mixes were prepared with moist sand (gravimetric water content approximately 5%). To saturate the cylinders, 2650 $cm^3$ of water (50% of the total rootzone volume) was added and the materials were left overnight. A further 2650 $cm^3$ was added the following morning.

### *Data collection*

*Water-release characteristics and saturated hydraulic conductivity of rootzone mixes at recommended rates of amendment materials.* Samples were taken from rootzone mix with recommended rate (RR), 50% of RR and 150% of RR and from pure sand for determination of saturated hydraulic conductivity and water retention using USGA methods (ASTM 2006). The range of tensions was extended to give a sequence of −1.0, −2.0, −3.0, −4.0, −5.0 and −6.0 kPa tension. Measurements were taken after 24 hours at each tension on a tension table using steel cylinders with the height 110 mm. For estimation of saturated hydraulic conductivity and water retention was measured at the different tensions using two replicates. The values at tension −4 kPa (water in capillary pores only) were used for estimation of available water. Part of the water in rootzones is tightly bound to the soil matrix and is referred to as 'dead water', and corresponds to permanent wilting point (PWP). PWP was estimated at pressure −1.5 MPa for 10 weeks using the pressure plate method (Dane and Hopmans 2002) in stainless steel cylinders (100 $cm^3$) in three replicates. PWP was determined for recommended (intermediate) rate of each amendment material only.

*Drainage and surface performance characteristics of rootzone profiles.* To monitor changes in water content during drainage, volumetric water content in the upper 60 mm was measured using a Theta probe. Initial measurements were made within the first minute after the ponded water had completely percolated into the surface of the rootzone. Further measurements were made after 1, 2, 4, 6, 24 and 48 hours. In all cases, three replicates were made per cylinder; for statistical analysis only the mean value from each cylinder was used.

After gravitational drainage for 48 hours, the surface was lightly compacted (one blow of the 2.82 kg mass from 0.39 m) to firm the surface after the theta probe measurements. Hardness was then measured using a Clegg soil impact tester (Simon Deakin Instrumentation Ltd., UK; 0.5 kg test mass released from 0.55 m). Three measurements of peak deceleration during impact were made per cylinder (each measurement on a different place). After the hardness measurements, shear strength was measured using a Geonor shear vane (Eijkelkamp Agrisearch Equipment, NL) fitted with four blades of 50 mm length and 12 mm width. Measurements were made in the area of impact from the hardness measurements as these areas had more uniform consolidation because of the greater compaction. The strength was measured over the top 50 mm of the profile.

*Water retention of rootzone profiles.* To determine the bulk density and the volumetric water content after gravitational drainage, the columns were excavated in increments of 50 mm. The exact height of each layer was recorded using six measured points from the top edge of the cylinder and the total weight of material removed was determined. A sub-sample of around 100–150 g was taken for measurement of gravimetric water content after drying at 105 °C. Bulk density was calculated as the dry weight of material per unit volume, and volumetric water content for each layer was calculated from bulk density × gravimetric water content. Water retention expressed in mm was calculated using water content in each layer and its height.

### *Statistical analyses*

Statistical analyses were performed using one way ANOVA (Statistica 8.1, StatSoft) for PWP and bulk density for the rootzones mixes with amendments incorporated at recommended rates, and two-way ANOVA for examination of water-retention data in upper and lower rootzones and for the effect of the lower rootzone layer on selected surface properties. Where appropriate the Fisher's least significant differences at the 0.05 level were calculated to indicate differences between the treatment means; confidence limits were calculated for data shown in figures. Surface shear strength and hardness data for the various rootzone profiles were expressed relative to the pure sand (=100) rootzone.

Table II. Saturated hydraulic conductivity and water retention characteristics (according to ASTM, F 1815-06) of individual mixes used for the experiment (standard deviation values are presented for the saturated hydraulic conductivity values due to more variable nature of this test method).

| | | | Water retention ($cm^3\ cm^{-3}$) at tensions from − 1.0 to − 6.0 kPa | | | | | |
|---|---|---|---|---|---|---|---|---|
| Treatment | Rate | Saturated hydraulic conductivity (mm $hour^{-1}$) | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 |
| Pure sand | 100% | 889 | 0.239 | 0.179 | 0.122 | 0.063 | 0.044 | 0.040 |
| Peat | 10% | 520 | 0.276 | 0.271 | 0.188 | 0.107 | 0.084 | 0.079 |
| | 20% | 449 | 0.336 | 0.329 | 0.246 | 0.163 | 0.139 | 0.130 |
| | 30% | 291 | 0.419 | 0.407 | 0.343 | 0.253 | 0.224 | 0.211 |
| Compost | 10% | 677 | 0.258 | 0.248 | 0.160 | 0.084 | 0.065 | 0.064 |
| | 20% | 664 | 0.287 | 0.275 | 0.202 | 0.111 | 0.088 | 0.087 |
| | 30% | 503 | 0.333 | 0.316 | 0.237 | 0.146 | 0.121 | 0.120 |
| Stockosorb | 0.5 RR | 638 | 0.264 | 0.256 | 0.165 | 0.089 | 0.069 | 0.068 |
| | 1.0 RR | 615 | 0.311 | 0.294 | 0.207 | 0.117 | 0.094 | 0.092 |
| | 1.5 RR | 515 | 0.345 | 0.328 | 0.243 | 0.148 | 0.113 | 0.124 |
| TerraCottem | 0.5 RR | 698 | 0.239 | 0.186 | 0.141 | 0.073 | 0.052 | 0.048 |
| | 1.0 RR | 646 | 0.248 | 0.200 | 0.148 | 0.081 | 0.061 | 0.056 |
| | 1.5 RR | 695 | 0.264 | 0.204 | 0.157 | 0.091 | 0.069 | 0.065 |
| Zeolite | 10% | 800 | 0.249 | 0.194 | 0.131 | 0.069 | 0.050 | 0.046 |
| | 20% | 808 | 0.264 | 0.199 | 0.130 | 0.076 | 0.060 | 0.058 |
| | 30% | 855 | 0.267 | 0.213 | 0.154 | 0.082 | 0.062 | 0.058 |
| $LSD_{0.05}$ | | 63.9 | 0.0014 | 0.0032 | 0.0012 | 0.0012 | 0.0015 | 0.0012 |

## Results

*Water-release characteristics and saturated hydraulic conductivity of rootzone mixes at recommended rates of amendment materials*

Water retention characteristics and saturated hydraulic conductivity of the mixes are shown in Table II. At a tension of −4 kPa (where capillary water is present only) all the amendments had greater water retention than the pure sand. Differences among rootzones in PWP and available water content are shown in Table III. In terms of available water-holding capacity, the Stockosorb mix had the most available water whilst the peat and TerraCottem had marginally higher available water content in comparison to the unamended sand. The zeolite mix had lower available water than the pure sand (likely to be due to the water being held within the crystalline structure). The mixes retaining the most water at −1500 kPa tension were those amended with peat and Stockosorb.

Table III. Water retention ($cm^3\ cm^{-3}$) at −4 kPa, −1500 kPa (PWP) and available water (AW) of a variety of amendment materials at recommended incorporation rates (standard deviations values are included when only two repetitions were used).

| | | Water retention | | |
|---|---|---|---|---|
| Amendment* | Bulk density (g $cm^{-3}$) | −4 kPa | −1500 kPa | AW† |
| Pure sand | 1.544 | 0.076 | 0.014 | 0.062 |
| Peat | 1.278 | 0.163 | 0.095 | 0.068 |
| Compost | 1.332 | 0.111 | x†† | x†† |
| TerraCottem | 1.543 | 0.081 | 0.013 | 0.068 |
| Stockosorb | 1.394 | 0.117 | 0.038 | 0.079 |
| Zeolite | 1.397 | 0.076 | 0.048 | 0.028 |
| $LSD_{0.05}$ | 0.055 | 0.0017 | 0.006 | |

†Available water was calculated as the difference between PWP and capillary water content at tension −4 kPa. Different samples were used for both estimations and LSD was not evaluated for AW.

††Data for the compost have not been presented as there were anomalies with the permanent wilting point value.

*Drainage and surface performance characteristics of rootzone profiles*

The soil water content values indicated that there was rapid drainage in the first hour following saturation but changes in water content of the mixes were much slower thereafter. The total difference in volumetric moisture content between sand and peat

Table IV. Volumetric water content ($cm^3\ cm^{-3}$) in top 60 mm of the profile, measured using a Theta probe as the rootzones mixes drain under gravity with amendments incorporated at recommended rates and in pure sand.

| | Time of drainage after saturation (hours) | | | | | | |
|---|---|---|---|---|---|---|---|
| Amendment | 0 | 1 | 2 | 4 | 8 | 24 | 48 |
| Pure sand | 21.5 | 8.1 | 6.9 | 6.6 | 5.9 | 5.9 | 5.5 |
| Peat | 36.6 | 15.1 | 13.7 | 12.8 | 12.3 | 11.6 | 11.8 |
| Compost | 34.7 | 14.4 | 12.6 | 11.5 | 10.9 | 10.4 | 10.1 |
| Terracottem | 26.9 | 10.2 | 9.0 | 7.7 | 7.2 | 7.5 | 7.0 |
| Stockosorb | 31.4 | 15.4 | 13.5 | 12.6 | 13.1 | 12.2 | 115 |
| Zeolite | 23.5 | 10.4 | 9.3 | 8.6 | 8.1 | 8.0 | 7.5 |
| $LSD_{0.05}$ | 4.4 | 3.1 | 2.7 | 2.5 | 3.0 | 3.2 | 1.8 |

Table V. Effect of amendment rate in the lower rootzone layer (150–300 mm) on selected surface properties (values averaged for all amendments and incorporation rates).

| | No amendment | 50% amendment | 100% amendment | $LSD_{0.05}$ |
|---|---|---|---|---|
| Volumetric water content 0–60 mm (%)* | 9.1 | 9.5 | 9.7 | 1.2 |
| Hardness (gravities) | 53.1 | 51.8 | 52.7 | 5.8 |
| Shear strength (kPa) | 6.03 | 6.08 | 5.79 | 0.85 |

*VWC was measured by Theta probe after 48 hours drainage.

treatments was 6.3% v/v after 48 hours in the top layer 0–60 mm (Table IV).

Table V shows the effect of increasing amendment rate in the lower rootzone layer on surface properties. In all cases there was no significant effect of the incorporation of amendment materials in the base layer on surface hardness or shear strength. In addition, no interactions between depth and amendment type or incorporation rate were recorded (data not shown).

Figure 1 shows that organic amendments (peat and compost) led to significantly greater shear strength, whilst the use of superabsorbents led to a decrease in shear strength. The highest values were determined at highest rate of peat (8.4 ± 1.5 kPa) while the lowest values were measured for the Stockosorb at the highest mixing rate (3.0 ± 0.25 kPa).

The softest surfaces were produced when the Stockosorb was incorporated into the rootzone (Figure 2). The lowest hardness values were determined at highest rate of Stockosorb in the upper layer (26.7 ± 7.3 gravities). The only amendment to increase surface hardness relative to unamended sand was Zeolite. The greatest hardness values were measured for zeolite at the highest rate in the upper layer (76.6 ± 14.2 gravities).

### *Water retention in rootzone profiles*

Individual amendment materials increased water retention in the upper rootzone unevenly. The greatest water retention was measured for the 30% sphagnum peat and the 1.5 × recommended rate of Stockosorb (Figure 3). Both these treatments increased water retention in the upper rootzone layer (150 mm) by 133% compared with pure sand (34 mm at Stockosorb rate 1800 g $m^{-3}$, 35 mm for 30% peat vs. 15 mm for pure sand). The lowest water retention was recorded for the TerraCottem amended rootzones, even when added at the highest rate (17 mm at 1.5 × recommended rate). As anticipated, water retention increased with increasing amendment rate.

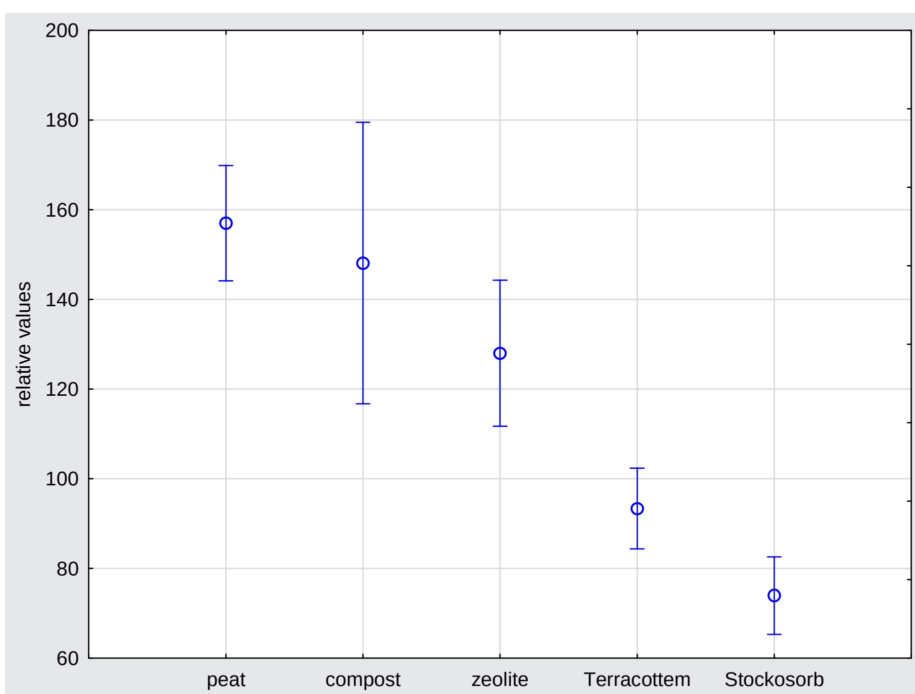


Figure 1. The differences in shear strength among used materials (pure sand = 5.0 kPa = 100); vertical bars show the confidence limits at $p = 0.05$.

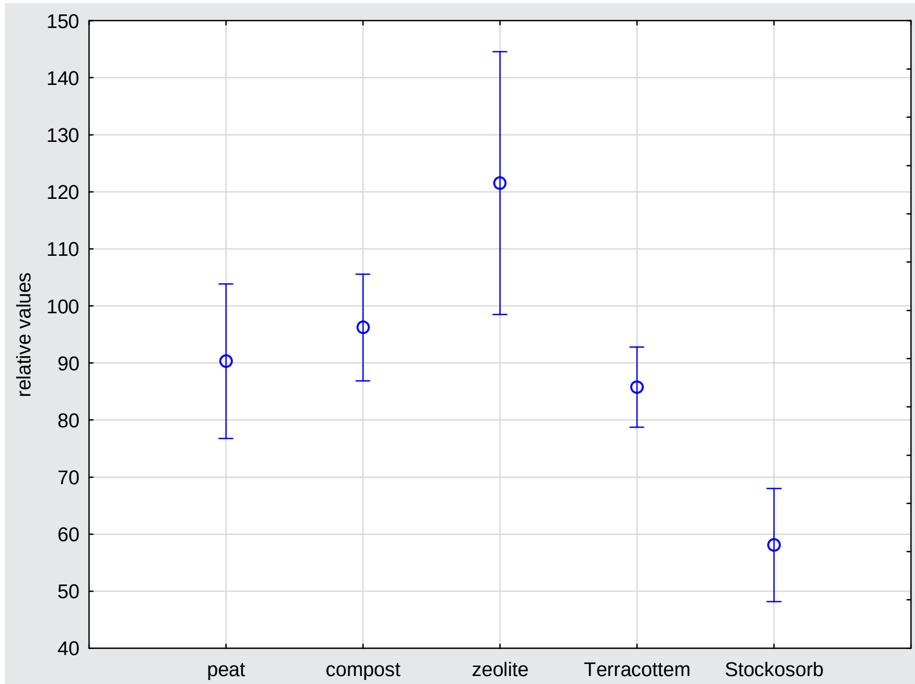


Figure 2. The differences in hardness among the used materials (pure sand = 59 gravities = 100%); Vertical bars show the confidence limits at $p = 0.05$.

The differences in water retention between the amendment treatments in the lower layer of the profile (150–300 mm) are given in Table VI. The difference between pure sand and the most retentive material was much smaller than for the top layer. Water retention of pure sand was 41 mm but the

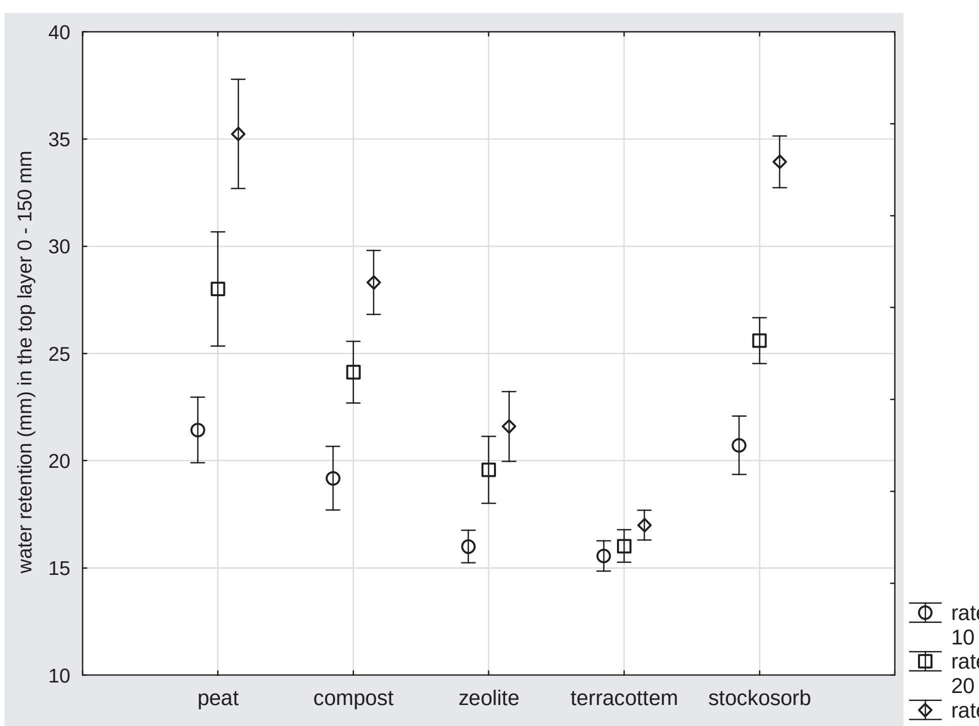


Figure 3. Effect of amendment materials and incorporation rate on water retention (mm) in the upper layer of rootzone (0–150 mm), vertical lines show the confidence limits at $p = 0.05$; water retention of pure sand layer was 14.6 $\pm$ s.d. 0.46. For Stockosorb and TerraCottem rate 10 means 0.5 recommended rate (RR), rate 20 = 1.0 RR and rate 30 = 1.5 RR.

Table VI. Effect of amendment materials and incorporation rate on water retention (mm) in the lower layer of rootzone (150–300 mm); water retention of pure sand layer was $41.3 \pm 0.6$ mm. For Stockosorb and TerraCottem rate 5 means 0.25 recommended rate (RR), 10 = 0.5 RR, 15 = 0.75 RR, 20 = 1.0 RR and rate 30 = 1.5 RR.

| | Amendment rate (v/v%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Amendment | 0 | 5 | 10 | 15 | 20 | 30 | Overall mean | $LSD_{0.05}$ |
| Peat | 41 | 42 | 44 | 46 | 49 | 57 | 47 | 0.95 |
| Compost | 41 | 41 | 41 | 42 | 46 | 48 | 43 | |
| Stockosorb | 41 | 43 | 44 | 47 | 48 | 55 | 46 | |
| TerraCottem | 41 | 40 | 41 | 42 | 44 | 44 | 42 | |
| Zeolite | 41 | 41 | 44 | 46 | 46 | 49 | 44 | |
| Overall mean | 41 | 42 | 43 | 45 | 47 | 50 | 44 | |
| $LSD_{0.05}$ | | | 0.96 | | | | | |

most retentive rootzone with 30% rate of peat contained just 57 mm of water which equates to a 39% increase. The interaction amendment × rate was significant (Table VII) as TerraCottem did not increase water retention in higher rates in comparison with lower rates. Of particular interest was the effect of varying rates of amendment in the lower rootzone on the water-retention characteristics of the upper rootzone and the whole profile (Table VIII and IX). Amendment rate in the lower rootzone had relatively little effect on the water-retention characteristics of the upper rootzone. On average the upper rootzone contained 1 mm more water when the lower rootzone contained amended material at the same rate as the upper rootzone compared with the situation when no amendment had been added to the lower rootzone. When the water retained in the whole profile was calculated, the effect of amending the lower rootzone was more pronounced. On average 7 mm of water was retained throughout the profile when the full rate of amendment was incorporated throughout the profile. However, the effect was not as strong for all amendment materials, as this difference in comparison with pure sand was smallest for zeolite and TerraCottem and largest for peat and Stockosorb.

## Discussion

A basic requirement for all sport fields is a fast drainage. Good drainage allows for the removal of large amounts of water in a short period of time and avoids cancellation or postponement of games due to waterlogging and excessively soft playing surfaces (Li et al. 2009). As shown in Table II, all mixes had sufficient saturated hydraulic conductivity, well above 150 mm hour$^{-1}$ as required according to USGA recommendations (2004). The good saturated hydraulic conductivity values were the result of the particle size distribution of the sand used in the rootzone mixes.

On the other hand rootzones should have sufficient water retention for grass plants' supply. Amendment type and rate of incorporation have a highly significant effect on the physical properties of the resultant rootzone mix. This is most clearly seen in the water-retention characteristics of the various rootzone mixes (Tables II–IV). Amending the lower rootzone increased the overall water retention throughout the entire 300 mm rootzone profile by an average of 7 mm, when comparing the full lower rootzone amendment rate with the unamended rootzone. This base layer effect was strongest for the peat, Stockosorb and compost amendments, whilst there was only a 1–3 mm increase in retention for the zeolite and TerraCottem amendments (Table VI).

The average water consumption of turfgrasses during sunny summer days in temperate zone climatic conditions is about 3–4 mm (Huang and Fry 1999, Beard 2002). Under these circumstances a 150 mm layer of pure sand would provide enough

Table VII. Analysis of variance results for water retention influenced by amendment materials and different rate in lower layer (data are related to Figure 3 and Table VI).

| | Upper layer (0–150 mm) | | | Lower layer (150–300 mm) | | |
|---|---|---|---|---|---|---|
| Source of variation | df | MS | p | df | MS | p |
| Amendment | 4 | 209.04 | 0.000 | 4 | 73.9 | 0.000 |
| Rate in lower layer | 2 | 222.05 | 0.000 | 5 | 187.5 | 0.000 |
| Amendment*rate in lower layer | 8 | 20.15 | 0.044 | 20 | 11.2 | 0.000 |
| Error | 30 | 8.63 | | 60 | 2.0 | |

Table VIII. Effect of amendment rate in lower rootzone on water retention in (a) the upper profile and (b) through the whole profile. The figures represent mean values for different amendment rates in the upper 150 mm.

| Rate of amendment in lower rootzone | Pure sand | Peat | Compost | Stocko-sorb | Terra-Cottem | Zeolite | Overall mean | $LSD_{0.05}$ |
|---|---|---|---|---|---|---|---|---|
| Total water held (mm) in upper 150 mm | | | | | | | | |
| No amendment | | 27 | 23 | 26 | 17 | 18 | **22** | 5.9 |
| Half rate of upper profile | | 28 | 24 | 28 | 16 | 19 | **23** | |
| Full rate of upper profile | | 30 | 24 | 27 | 16 | 19 | **23** | |
| Overall mean | 14 | 28 | 24 | 27 | 16 | 19 | **23** | |
| $LSD_{0.05}$ | | | | | | | | |
| Total water (mm) held in full profile (0–300 mm) | | | | | | | | |
| No amendment | | 68 | 64 | 67 | 57 | 60 | **63** | 8.4 |
| Half rate of upper profile | | 72 | 66 | 73 | 57 | 63 | **66** | |
| Full rate of upper profile | | 80 | 69 | 76 | 59 | 65 | **70** | |
| Overall mean | 56 | 73 | 66 | 72 | 58 | 63 | **66** | |
| $LSD_{0.05}$ | | | | 8.5 | | | | |

soil water for 4–5 days while the most retentive treatments could provide water for 9–12 days. However, not all the water in a rootzone is available to plant roots. Table III shows considerable differences between rootzone mixes in water retention and available water-holding capacity. However, estimation of PWP is very time consuming and requires specialist equipment. Additionally, Bigelow et al. (2004) found that the pressure plate method is not always suitable for water availability estimation, as if there are discontinuous pores in the rootzone the plants are still able to extract water, but it is not released during the pressure plates measurement. However, the pressure plate method remains the standard test procedure for the determination of PWP, which is why this procedure was used in this experiment. Nevertheless it should be used for consolidated soil samples.

One of the important findings, supported by the water-retention data, was that after gravitational drainage had finished, the amendment rate of the lower 150 mm of the rootzone profile had no significant effect on the amount of water held in the upper rootzone. This would indicate that in wetter climates or where a good irrigation system is available the amendment of the whole profile is probably not necessary. Additionally, the bulk of the turfgrass root mass tends to be located in the upper 150 mm of the profile, further adding to the argument against the need to amend the lower rootzone. If the lower rootzone was not amended the overall cost of constructing high-performance sand-based profiles would be reduced as the cost per tonne of sand is substantially less than that for a rootzone mix. Additionally if too much water is retained in the rootzone anaerobic conditions can occur which are detrimental for root growth and general turf health. In terms of surface performance characteristics, amendment type did have a significant effect on the shear strength and the hardness of the rootzone. The shear strength of a rootzone is important particularly when rounded sands with a uniform grain size are used and if turf cover is reduced through wear damage. This property is particularly important to players especially for sports such as football. Shear strength values were greatest for the organic amendment materials (peat, compost). Decrease in rootzone mechanical strength, when the superabsorbents were used, was caused by swelling of the polymer which reduced the packing density of the rootzone and therefore reduced interparticle-friction. The optimal values for consolidated sports' rootzones with established turf are 10–20 kPa (Baker and Richards 1993). Measured values in our trial were lower due to non-consolidated rootzones.

Hardness of the rootzones influences the playability of the sport surfaces. This property is commonly measured on sports turf surface golf greens (Baker and Canaway 1993, Baker et al. 1997), football pitches (Spring and Baker 2006, Baker et al. 2007)

Table IX. Analysis of variance results for amendment materials and different rate in lower layer (data are related to Table VIII).

| | Upper layer (0–150 mm) | | | Whole rootzone (0–300 mm) | | |
|---|---|---|---|---|---|---|
| Source of variation | df | MS | p | df | MS | p |
| Amendment | 4 | 701.5 | 0.000 | 4 | 1097.2 | 0.000 |
| Rate in lower layer | 2 | 16.6 | 0.463 | 2 | 530.5 | 0.000 |
| Amendment*rate in lower layer | 8 | 4.9 | 0.985 | 8 | 36.3 | 0.574 |
| Error | 120 | 21.5 | | 120 | 43.5 | |

and artificial turf (Baker 1990, Baker et al. 1996). Increased surface hardness of an athletic field results in a greater risk of athlete injury in the event of a fall (Baker and Canaway 1993). Reduction in surface hardness can lead to problems with low ball bounce and a surface that is more prone to wear. High hardness of zeolite mixes was probably a result of the angular grain shape of the material leading to greater inter-particle friction. For a typical inland golf green, hardness values should be between 80–100 gravities (STRI, Internal Agronomy Service Guidelines). The lower hardness values measured for the different rootzones during the trial reflected the degree of rootzone consolidation used in the experiment, but provided a true comparison under controlled conditions between the various rootzone mixes. McNitt and Landschoot (2003) stated that surface hardness was affected to a much greater degree by bulk density than by water content. This may be the case under drier conditions, but the relationship between surface hardness and soil water content is very strong and is usually the dominant controlling factor. Different moisture content of individual mixes probably influenced also the results in our experiment.

Surface hardness of the various rootzone mixes was significantly affected by the type of amendment incorporated into the rootzone. The Stockosorb amended mixes were significantly softer than the other treatments because of the quantity of the polymer in the rootzone mix. This resulted in an increase in volume of the rootzone when the granules swelled when they absorbed water. Mixes containing the zeolite were harder that the other mixes.

## Conclusions

There were significant variations in the water-retention properties of the different amendment materials and water retention was highly dependent on incorporation rate. The most water-retentive mixes used in the study were those containing the superabsorbent Stockosorb, sphagnum peat and compost. Mixes amended with zeolite and TerraCottem held the least water.

The effect of depth of amendment did not significantly affect water retention in the upper 150 mm of the profile, once gravitational water had drained away. Where irrigation infrastructure is good and under wetter climatic conditions there is no advantage to incorporating rootzone amendments through the whole profile. There should be a cost benefit as a result of not having to amend the whole profile as pure sand is cheaper than rootzone mixes.

Amendment material did influence rootzone shear strength and surface hardness. The mixes amended with organic materials were stronger than the other mixes and use of superabsorbent polymers caused a reduction in shear strength. Of all the mixes the zeolite had the greatest hardness values, probably as a result of the more angular nature of the granules leading to greater inter-particle friction.

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