Středová, H., Rožnovský, J., Litschmann, T. (eds): Mikroklima a mezoklima krajinných struktur
a antropogenních prostředí. Skalní mlýn, 2. – 4.2. 2011, ISBN 978-80-86690-87-2

SOIL WATER AND TURFGRASS GROWTH UNDER DEFINED CLIMATE AND SOIL CONDITIONS

Margarita Himmelbauer, Helene Rieckh, Willibald Loiskandl

Institute of Hydraulics and Rural Water Management, Dept. of Water, Atmosphere and Environment, University of Natural Resources and Life Sciences, BOKU Vienna, Muthgasse 18, 1190 Vienna, Austria

Abstract

Soil water is an important factor to control turfgrass growth. Turfgrasses generally have shallow root systems, therefore they are vulnerable to soil drought. Plants may overcome soil water shortage by either preserving the roots longer vital or extended root growth in moist soil regions. Due to a growing interest in water saving practices in parks and golf courses, the question of how to maintain high quality turfgrasses with applying less irrigation water rises. Using subsurface drip irrigation combined with soil amendment considered to increase soil water holding capacity, water applications can be reduced on the account of minimised water losses along with keeping the cover green. The objective of this study is to evaluate the performance of a specific combination of subsurface drip irrigation and inorganic soil amendment on clay mineral basis.

First results of ongoing experiments in a climate chamber are presented. Modifications of the common sand-based profile in golf courses, adding different percentages of the amendment to the sand, are tested. Cool-season turfgrass species are grown on the test profiles under defined climate conditions. Special boxes have been constructed for simultaneous observation of water movement and root growth. The boxes are equipped with TDR and pressure probes spaced around the emitter and down the profile to assess the distribution of the water content and the pressure head. In addition, turfgrass cover growth is monitored.

Addressing obtained data, water storage and movement are analysed and compared with the simulation of the water dynamics conducted with HYDRUS 2D/3D. The results for humid and arid climate conditions are discussed in respect to water saving strategies using subsurface irrigation.

Keywords: climate chamber, turfgrass, amended rooting zone, subsurface drip irrigation and HYDRUS simulations

Introduction

Owing to a growing interest in water saving practices in recreation areas including golf courses, the question of how to maintain good quality turfgrass cover applying less irrigation water nowadays rises. Turfgrasses generally have shallow root systems. For this reason, they are highly susceptible to water shortages especially near the soil surface. Permanent water deficiency affects visual quality (colour), rate of shoot and root growth, evapotranspiration demands of the grasses, etc. At the same time, it has been reported that turfgrasses may tolerate certain levels of soil drought with negligible quality failure. Drought resistant cultivars can overcome soil water shortage by either minimised transpiration needs via physiological adaptations or extending the root growth in moist soil regions (Githinji et al., 2009). For cool season grasses with low mowing heights as on greens and tees golf areas it was rather observed that the differences in water consumption are negligible (Leinauer et al., 2004).

Alternative water saving strategy relate to application of advanced irrigation techniques along with more precise scheduling based on plant or soil water status measurements. Due to its low evaporation losses, subsurface drip irrigation (SDI) is assumed to be a very efficient irrigation approach which conveys water directly to the roots. More over, the subsurface water application supports grass deep rooting. The extended rooting depth in turn ensures that turfgrasses are able to take water and nutrients from greater soil volume and thus helps the plants to resist soil surface droughts.

Putting green profiles in golf courses are normally constructed using coarse and medium size sands in certain proportions. The sands provide favourable conditions for root growth in terms of good aeration, enhanced hydraulic properties and drainage, etc. (Bilelow et al., 2004). On the other hand, they have low retention capabilities leading to water and nutrient leaching and subsequent stress for the plants. Using organic and inorganic soil amendments is an optional method of increasing plant available water capacity of the sands (Waltz et al., 2003; Leinauer & Makk, 2007). At present, many inorganic soil amendments have been marketed, i.e. porous ceramics, diatomaceous earth, zeolites, clay minerals, etc. (Bigelow et al., 2004). Combining the advantages of subsurface drip irrigation and soil amendments, irrigation water can be saved along with keeping the grass cover green.

The main objective of the ongoing study is to evaluate the performance of a combination of subsurface drip irrigation (SDI) and a specific inorganic soil amendment mixed in different proportions with the golf sands. Particular objectives are, first: to assess the water storage, movement and evapotranspiration of turfgrasses grown on amended and unamended sand-based profiles at three irrigation levels, and second: to compare the results with numeric simulations of water movement for scenarios with and without amendment for humid and arid climate conditions.

Materials and methods

A special SDI-system, proposed by the Hydrip GmbH, is currently tested at the Institute for Hydraulics and Rural Water Management, BOKU, Vienna in a framework with the enterprise. The system comprises subsurface drip irrigation and an utilisation of Betasoil, an inorganic amendment on a clay mineral basis. The experiments are designed to study combined effects of amended putting green rooting zones and irrigation regimes on growth and water needs of turfgrasses under humid and arid climate conditions in a climate chamber.

Rooting media (sand-based profile) is constructed using different size washed sands and gravel partitioned into layers following the United State Golf Association instructions (USGA, 1993). Two modifications of the common profiles, mixing 2 and 5 mass percentages of the Betasoil amendment with the sand in the layer surrounded the irrigation emitter (called Bt2 and Bt5) are tested. The choice relays on a preliminary examination of physical and hydraulic properties of Betasoil plus conducted cost-benefit analyses (SINAPSIS Interim report, 2010). The conventionally build putting green profile without amended layer, *i.e.* Sd treatment, serves as a control.

Six boxes (two boxes per treatment) have been constructed for simultaneous observation of water movement, plant and root growth. The boxes (50 x 55 x 6 cm) are made from hard plastic or PVC combined with clear acrylic (Plexiglass) front (Fig. 1). The plexiglass face is covered with a removable black cloth to protect roots from light exposure. The boxes are equipped with regularly spaced TDR and pressure probes to monitor changes in soil water content and pressure head around the dripper and through the rooting zone. Both parameters are used to evaluate water movement and uptake (actual evapotranspiration). Inflow (pumping rate) and outflows (water tank on a scale) are recorded in minute steps. Thus, water balance of the system is acquired.

A turfgrasses cultivar mixture of Bentgrasses: Browntop bent (*Agrostis capillaries*) and Creeping bent (*Agrostis stolonifera*), and Fescues: Chewings fescue (*Festuca rubra commutate)* and Red fescue (*Festuca rubra trichophylla),* is grown on the boxes. These cool-season grass species are widely used in golf putting greens in Austria. Sod pieces (ca. 2 cm dick) are collected from two-year old turfgrass area in a golf course near Linz. Sods downside (roots) is washed free of soil before planting. Next, the sods are put on the top of the preliminary saturated and drained test profiles, gently pressed and watered from above to facilitate the initial rooting. Controlled-release fertilizer (18N-24P-12K) has been top dressed. Further, turfgrass cover and root growth are monitored. Turf is hand clipped weekly at about 1.5-2 cm height, clippings are collected and dried (60ºC). Roots will be sampled at the end of the experiment.

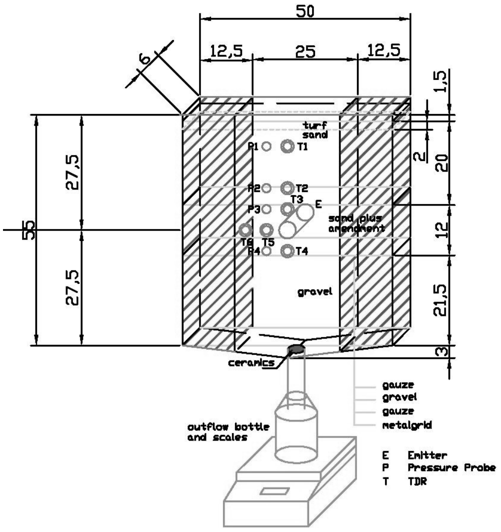

Fig.1 Experimental boxes for tests in climate chamber

The turfgrass boxes are irrigated based on the estimated potential turfgrass evapotranspiration (ET). The well known method for the estimation of Etc, involving a calculation of the reference ET (ETo) and then applying a suitable crop coefficients (Kc), is used in this study. The reference evapotranspiration is estimated on a basis of weather conditions of an experimental golf area near Linz, using Penman-Monteith equation (Allen et al., 1998). The weather parameters averaged for the last 10 summer periods from May to September (irrigation periods) are also used for a humid climate adaptation in the climate chamber (see below). The potential turfgrass ETc was calculated by multiplying the reference ETo with the averaged crop coefficient for cool-season turfgrasses of 0.8 (Allen et al., 1998; Carrow, 2006).

Three main irrigation levels corresponding to 100 % (full irrigation), 75 %, and 50 % (deficit irrigation) ET-replacement are examined. The irrigation levels (sums of drip irrigation water and top watering considered as rainfall) are applied first on a daily basis, later on 3 times per weak one after another for a period of at least 2 weeks. Irrigation water is pumped out from the underground tube at a rate of 1 lh^{-1}. The drip irrigation tube is positioned ca. 25 cm beneath the soil surface (Fig. 1). In addition, during the first weeks after sod planting, the boxes are watered from above to ensure turfgrass rooting into the testing profile, which is accounted as a 150 % ET-replacement level (high irrigation).

For the experiments under humid conditions in the climate chamber, the turfgrasses are grown with maximum/minimum (day/night) temperatures of 24/15° C and relative humidity of 56/80 % achieved gradually. The light regime is supplemented by metal halide lamps placed about 0.5 m above the turf canopy. The lights are turned on at 6 h and off at 20 h. Photosynthetically active radiation (photosynthetic photon flux density) on a horizontal plane just above the canopy approximates 400 μmol m^{-2} s^{-1}.

The experiments are still in progress. For that reason simulation of the water dynamics are additionally conducted with HYDRUS 2D/3D (Simunek et al., 2006). Water storage and movement and uptake in the tested sand profiles (Sd, Bt2, Bt5) are simulated for the three main irrigation levels (100 ET, 75 ET and 50 ET) for a period of one month under humid and arid climate conditions.

Results and Discussion

A short overview of the experimental set-up in the he current investigation:

- three sand-based profiles (treatments): Sd, Bt2 and Bt5 in two replications tested in Boxes 1 to 6;
- three main irrigation levels applied based on 100ET, 75ET and 50ET- replacement;
- growing the turfgrasses under two climate conditions.

First experimental results for high and full irrigation levels show that the adding of the soil amendment decreases water losses via drainage, while the soil water holding capacity increases. Soil water content measurements in modified profiles are higher than the control (Sd) in both the amended layer round the emitter and in the top sand layer were the initial root growth occurs. As a result, the modified golf profiles (Bt2 and Bt5) exhibit higher proportion of stored as well as of plant available water reserved over longer time compared with the control with pure sand profile (*e.g.* in Fig. 2).

The plant available water (PAW) is calculated as a difference between water held at -15000 mbar (wilting point, WP) and at field capacity (FC). The filed capacity water refers to that one left after the gravitational water is drained and a downward movement is insignificant. In this study and for the soil conditions in the test boxes, the FC- matric head value was determined to approximate -20 mbar, readings measured 3 days after a full saturation and a drainage of the six boxes. According to the retention curves, it corresponds to 20.2, 24.5 and 25.6 volumetric water content for Sd, Bt2 and Bt5 - treatments, respectively. Other studies however, report FC to be lower, *i.e.* between -40 and -300 mbar (*e.g.* Githinji et al., 2009). According to Doorenbos et al. (1986), a threshold value for irrigation timing termed onset of stress is defined when 50 % of the available water are reached. Number “50” in Fig. 2 stands for water held in the profile at -50mbar. At this matric head a half of the total available water remains in the Sd and Bt2 -treatments, while for the Bt5 ones there is still 70 % of PAW presented. The 50%- PAW limit here is achieved at -100mbar.

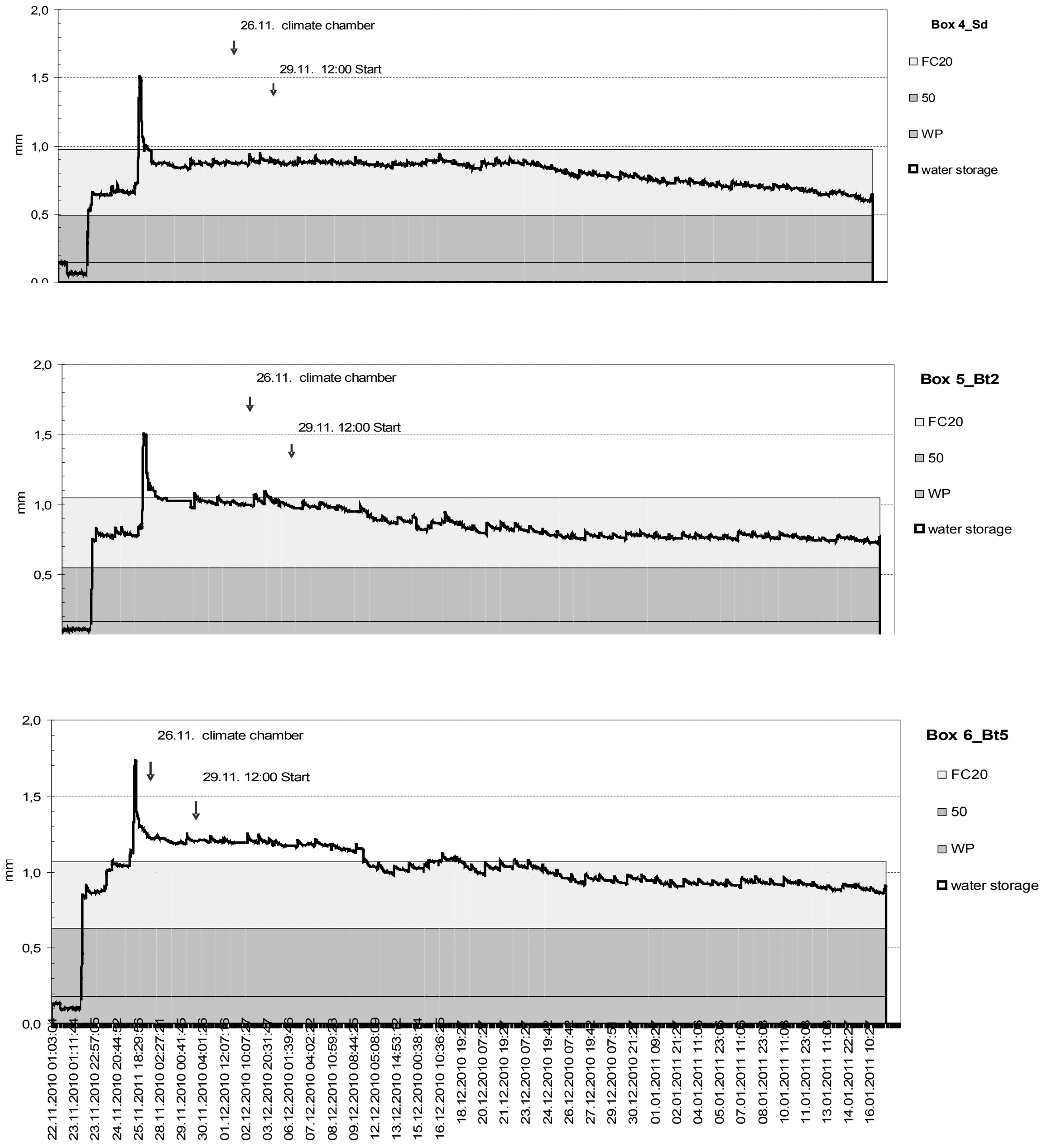

Fig. 2 Water storage in the tested profiles during the high and full irrigation levels. Sd- sand profile (control), Bt2- with 2 % amendment and Bt5 with 5 % amendment. FC20 stands for field capacity at -20mbar matric head, “50” represents water stored at -50mbar, WP- wilting point.

The matric heads measured at four depths per treatment are presented in Fig. 3. The measurements close to the dripper at 31 and 21 cm depths within the amended layer vary slightly according only to the irrigation events. Thus, no significant influence of the added amendment is to be observed here at high and full irrigation levels. The measurements close to the soil surface at 6 cm depth show the highest variation due to the evapotranspiration, watering and uptake by the turfgrass roots. The soil evaporation was assumed to be negligible, since the turfgrass sods were completely developed and cover the whole box surface. In addition, at the shallow depths are the largest differences between the treatments observed. The most negative values (low matric heads) are measured in the top 6 cm depth of the control. In contrast, the measured matric heads of the top of the modified profiles do not exceed -50 cm. As already mentioned, this matric head corresponded to the low limit for irrigation timing for the sand boxes.

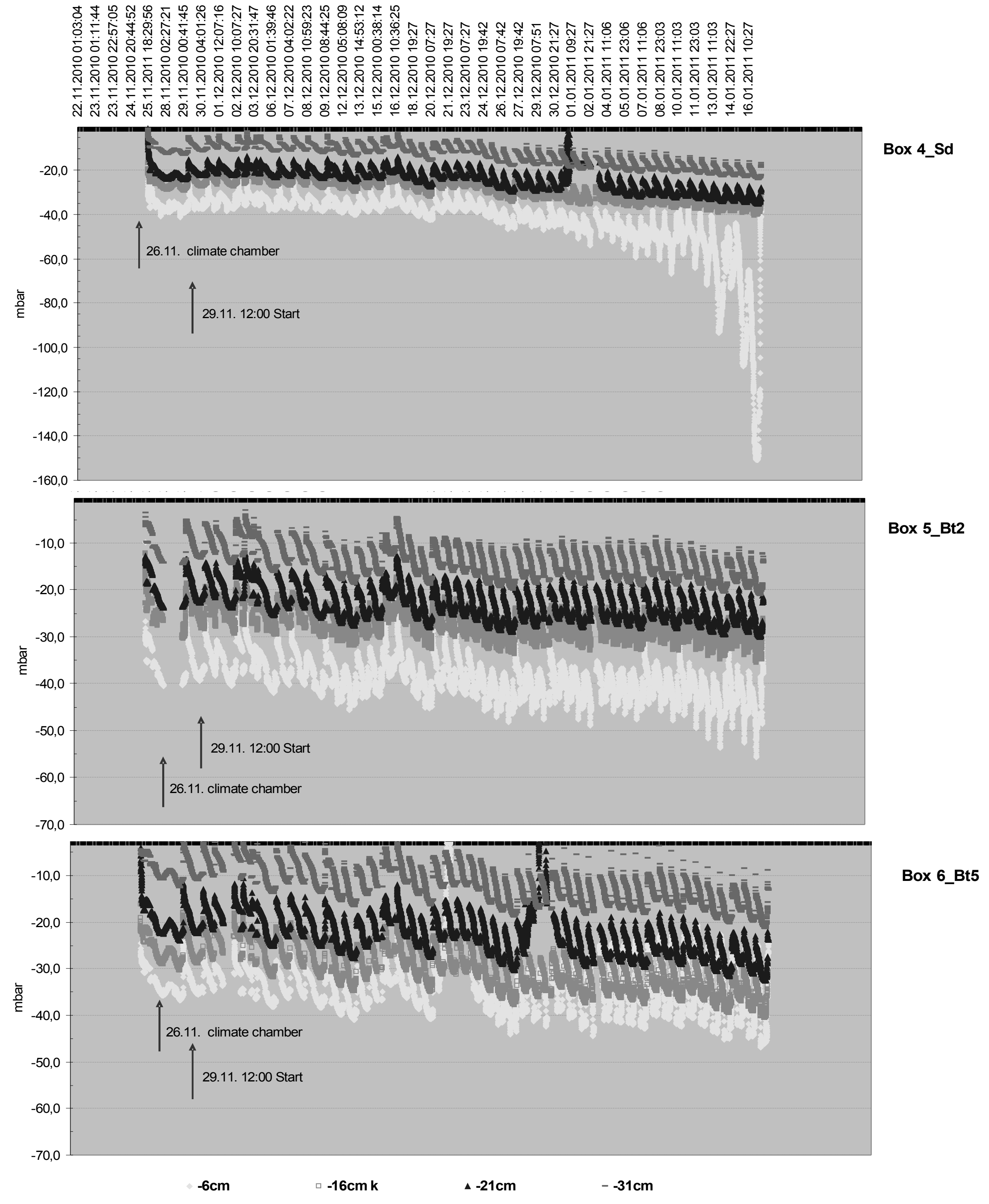

Fig. 3 Matric heads measured at different depths in the tested profiles during the high and full irrigation levels. Sd- sand profile (control), Bt2- with 2 % amendment and Bt5 with 5 % amendment.

Locking at the Fig. 4 one can see, the incorporation of the soil amendment to the sand profiles significantly reduced the seepage water. The cumulative water outflows of the Bt5 -boxes are less that a half of the water outflow sums for the controls. The results for the Bt2-treatment lay in-between. It should be mentioned, that the results for the control boxes differed. After initially high outflow rate in the Box 4, it the drastic diminished over time.

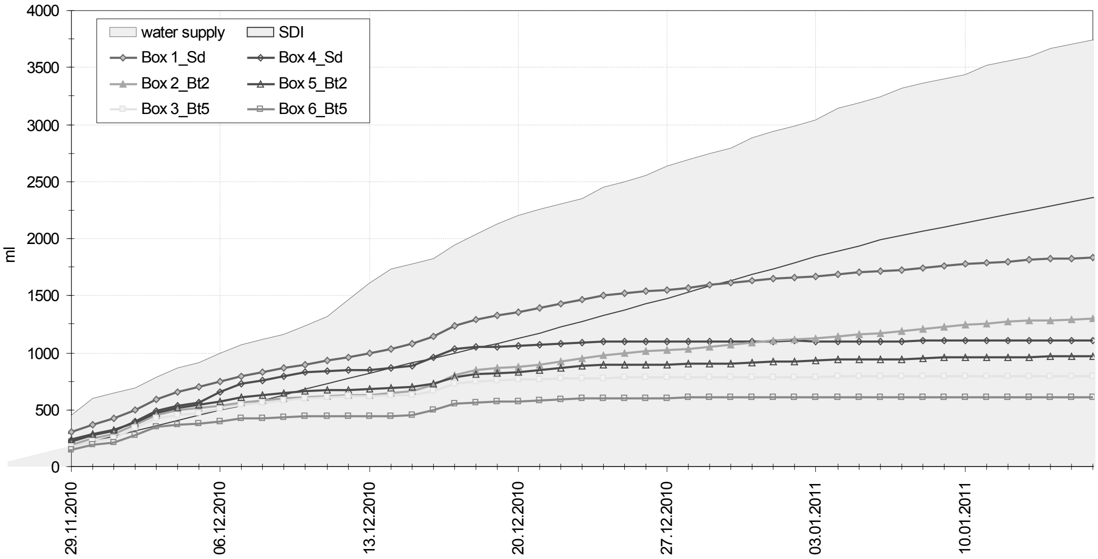

Fig. 4 Comparison between the cumulative water supply, drip irrigation (SDI) and outflow water sums for the 6 test boxes. Sd- sand profile (control), Bt2- with 2 % amendment and Bt5 with 5 % amendment

The values of the actual turfgrass evapotranspiration (Eta) are estimated using a balance method as a difference between daily water supply, water outflow and changes in the volumetric water contents (TDR readings) in each Box. The results of the cumulative Eta are shown on Fig. 5 and Eta weekly sums on Fig. 6a.

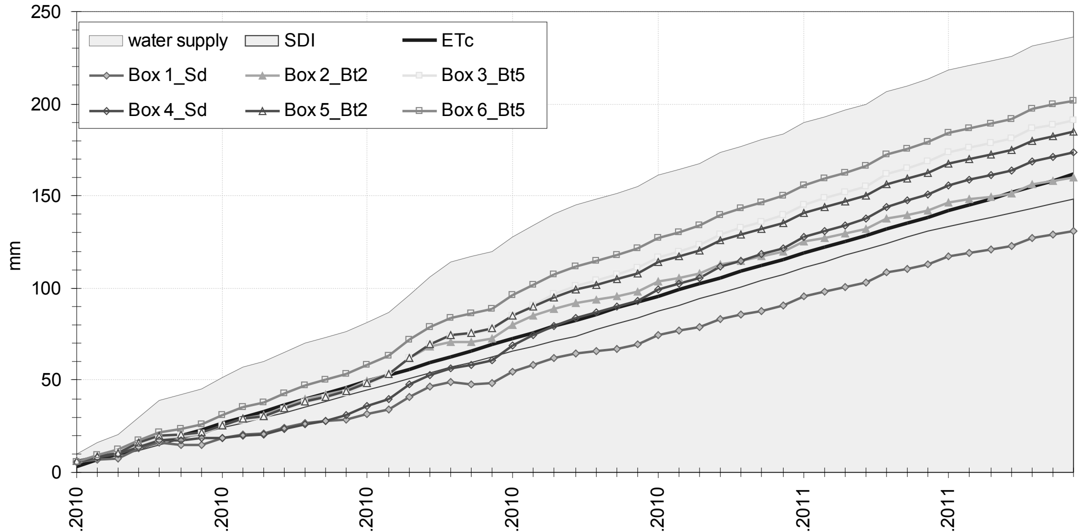

Fig. 5 Comparison between the cumulative water supply, drip irrigation (SDI), potential evapotranspiration (ETc) and actual evapotranspiration estimated for the 6 test boxes. Sd- sand profile (control), Bt2- with 2 % amendment and Bt5 with 5 % amendment

Corresponding to the previous results, the highest Eta- values are found in the boxes with application of 5% amendment (Bt5).The Eta- values for the controls, the Box 4 with less water looses increased highly over time and at the end of the observed period of 7 weeks are larger than those in the Bt2 treatment, *i.e.* Box 2 and 5. Looking at evapotranspiration rates on a weekly basis (Fig. 6a) one can see that the box- Eta' exceed the potential ETc in the third week (high irrigation), and approached it again during the last observed week (full water supply but 75 % of the SDI). Just the control Box 1 keeps below the potential ET- value of 3.3 mm/day, however showing less time variations compared to the other boxes.

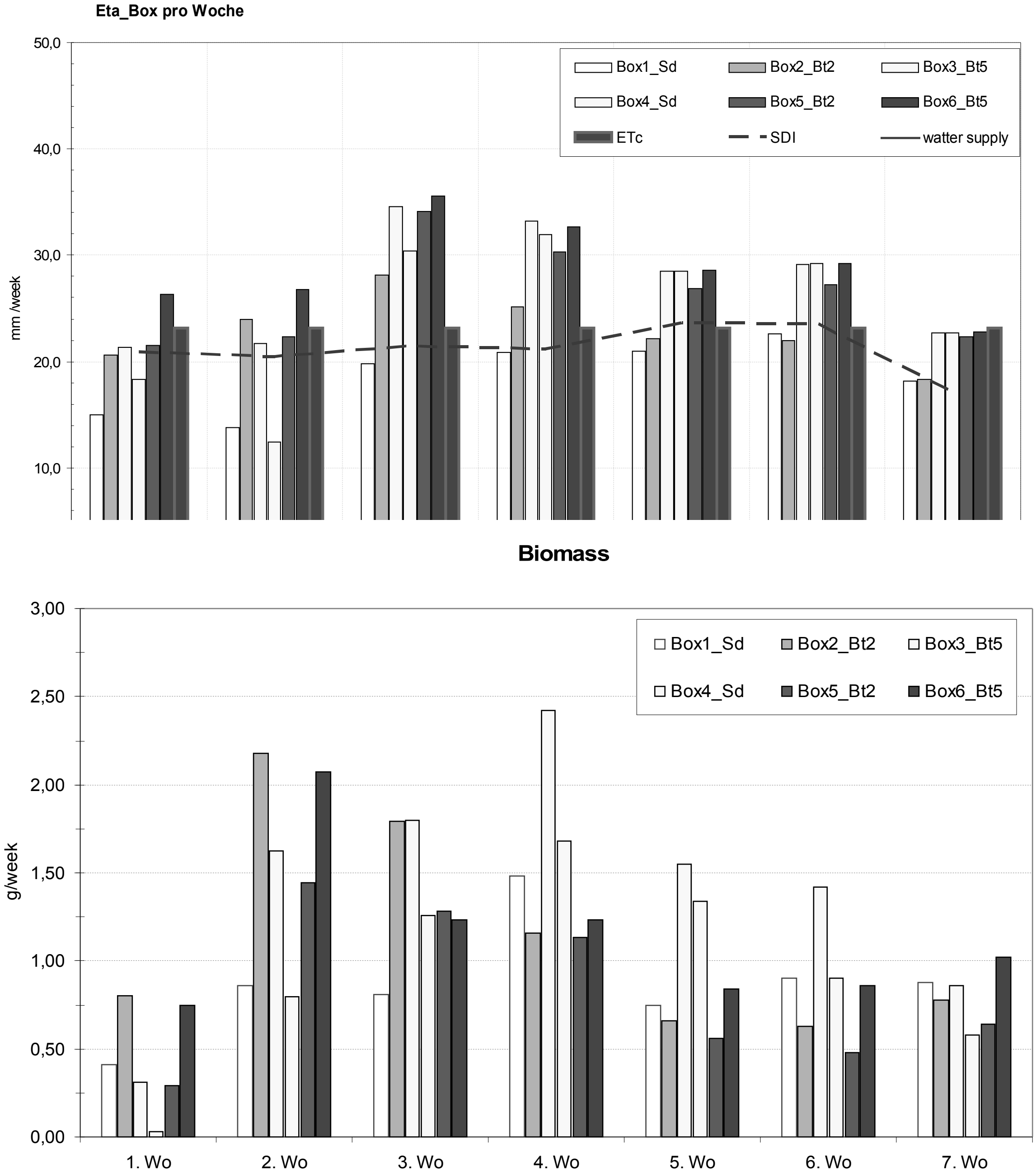

Fig. 6 Comparison between a) potential evapotranspiration (ETc) and actual evapotranspiration and b) biomass growth rate on a weekly basis for the 6 test boxes. Sd- sand profile (control), Bt2- with 2 % amendment and Bt5 with 5 % amendment

The results for the Box 2 with Bt2 –profile also significantly decreases at the end of the observed period, showing some sensibility against reduced irrigation level. In addition, it was observed that the growth rate of the newly planted turfgrasses sods also decreased with the

time, and in the BT2-boxes is even worse than in the control ones (Fig. 6b). The turfgrass growth rate on the Bt5-amended boxes is mostly higher, but surprisingly, the differences diminished over time.
As well known, the ET reflects the weather conditions, while the crop coefficient represents the plant growth status on account of the management and irrigation practices. Te estimated actual crop coefficient Kc of turfgrass is mainly higher that considered one of 0.8 except for the control Box 1. In contrast, the values for the Bt5-treathment are between 0.9 and 1.2.

The experiments are still in progress, that's why for the deficit irrigation and arid climate conditions scenarios we conduct simulations with HYDRUS 2D/3D. The input parameters for the HYDRUS simulation are presented in Table 1.

Table 1 Input parameters used for the HYDRUS simulation:

Soil medium	θr	θs	ψ (cm)	σ (-)	Ks (cm/h)	l (-)
Sand	0,30	0,42	17,00	1,20	40,50	0,50
Bt2	0,04	0,39	25,20	1,10	32,38	0,50
Bt5	0,05	0,41	27,00	1,71	16,76	0,50

θ_r is residual soil water content
θs is saturated soil water content
ψ and σ are parameters of the Kosugi soil water retention function
Ks is saturated hydraulic conductivity
l is tortuosity parameter

For the simulations the water retention model of Kosugi is used (Kosugi, 1996). Potential evapotranspiration for the humid conditions is considered to be 3.5 mm/day and 7.0 mm/day for arid conditions respectively. It occurs over 14 hours each day. The simulation period is 30 days for each of the irrigation levels, *i.e.* 100 %, 75 % and 50 % ET-replacement.

Table 2 Output parameter for water content (cm^3/cm^3) in 6 and 26 cm depth at the end of the simulation period

6 cm	**Sd**	**Bt2**	**Bt5**
100 ET	0,0774	0,0748	0,0792
75 ET	0,0757	0,0732	0,0773
50 ET	0,0736	0,0713	0,0750

26 cm	**Sd**	**Bt2**	**Bt5**
100 ET	0,1010	0,1293	0,1826
75 ET	0,0976	0,1251	0,1788
50 ET	0,0933	0,1214	0,1745

Table 3 Output parameter for pressure head (cm) in 6 and 26 cm depth at the end of the simulation period

6 cm	**Sd**	**Bt2**	**Bt5**
100 ET	-68,97	-71,98	-66,87
75 ET	-70,97	-73,85	-69,11
50 ET	-73,32	-76,04	-71,70

26 cm	**Sd**	**Bt2**	**Bt5**
100 ET	-50,56	-52,72	-48,62
75 ET	-52,51	-54,62	-51,00
50 ET	-55,10	-57,15	-53,70

As expected, water content and pressure head values decrease along with reduced irrigation rates for all simulated profiles (Tab.2 and Tab. 3). Surprisingly, the modified Bt2 profile shows less final water content than the pure sand profile. Bt5 shows the highest water content and the lowest pressure head (less negative) for both observation points on the top and the bottom root zone compared to Sd and Bt2 for all three irrigation levels. Nevertheless, the differences in the output values between the profiles and irrigation levels are not considerable. The same trends are observed by the simulations under arid conditions.

In order to clarify to which extend the soil amendments and reduced irrigation rates can be introduced in the praxis further experimental and simulation work is intended.

Dedication
This study is financed by the COIN Program of the Austrian Research Promotion Agency (FFG), (PN 822826).

References

Allen R.G., L.S. Pereira, D. Raes, and M. Smith (1998): Crop Evapotranspiration: Guidelines for computing crop water requirements." Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome.

Bastug R. and D. Buyuktas (2003): The effects of different irrigation levels applied in golf courses on some quality characteristics of turfgrass. Irrigation Science, 22: 87–93

Bigelow C.A., D.C. Bowman, K. Cassel (2004): Physical properties of three sand size classes amended with inorganic materials or sphagnum peat moss for putting green root zones. Crop Science, 44: 900–907

Carrow, R.N. (2006): Can we maintain turf to customers' satisfaction with less water? Agricultural Water Management, 80:117–131

Doorenbos J., Kassam, A.H., Bentvelsen, C.L.M., Branscheid, V., Plusje, J.M.G.A. (1979): Yield response to water. In: FAO Irrigation and Drainage Paper (FAO), no. 33 / FAO, Rome (Italy). Land and Water Development Div. 1979, 200 p.

Githinji L J. M., J H. Dane and R. H. Walker (2009): Water-use patterns of tall fescue and hybrid bluegrass cultivars subjected to ET-based irrigation scheduling. Irrigation Science, 27: 377–391

Himmelbauer M, I. Kogelbauer, A. Schwen, R. Nolz, W. Loiskandl (2010): Sinapsis Project, Interim Report.

HYDRIP GmbH (Information available at http://hydrip.at/)

Kosugi K. (1996): Lognormal distribution model for unsaturated soil hydraulic properties, Water Resour. Res., 32(9): 2697-2703

Leinauer B. and J. Makk (2007): Establishment of Golf Greens under Different Construction Types, Irrigation Systems, and Rootzones. In: J. Nus (Ed.): United States Golf Association (USGA): Turfgrass and Environmental Research Online, Vol. 6, Nr. 7, April 2007. ISSN 1541-0277

Leinauer B., R. Sallenave, and H. Schulz (2004): A comparison of construction types and their associated irrigation systems: Effect on turfgrass quality, drought avoidance, and irrigation water use. Acta Horticulturae 661 (Nov.): 123-129 (TGIF Record 101828)

Simunek, J., van Genuchten, M.T., and Sejna, M. (2006): The HYDRUS Software Package for Simulating the Two- and Three-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media. Technical Manual PC Progress, Prague, Czech Republik

United States Golf Association (1993): USGA recommendations for a method of putting green construction. USGA Green Section. Agronomy Journal, 52: 569–572

Waltz FC Jr, V.L. Quisenberry and L.B. McCarty (2003): Physical and hydraulic properties of root zone mixes amended with inorganics for golf putting green. Agronomy Journal, 95: 395–404

Contact address of the first author: Margarita Himmelbauer, University of Natural Resources and Life Sciences, BOKU Vienna, Muthgasse 18, 1190 Vienna, Austria; Email: ml.himmelbauer@boku.ac.at