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Aspects of incorporating biodegradable textiles to improve sports turf

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Table of Contents

List of table

List of figures

1 Introduction

1.1 Problem definition

Soccer, one of the most popular sports worldwide, is performed on turf surfaces especially designed for this purpose. In Germany 55,072 soccer fields were in use in the year 2000 (Senatsverwaltung für Bildung, Jugend und Sport et al. 2002). Wherein 33,139 are classified as large soccer fields, with a size of at least 7,000 m² (DFB 2011). Since these surfaces are in use during all seasons, they must be playable under most weather conditions. Turfgrass for this purpose is normally is established on an artificial layer-by-layer system. High water permeability is necessary to enable drainage after heavy rainfall. Many sport fields are also used in winter and therefore have to drain larger amounts of water (Hatfield 2017). On the other hand, a sufficient water supply of the turfgrasses is a major challenge for planning and constructing sport fields (Huang 2008; Leinauer et al. 2012). Turf surfaces are subject to stress from play and maintenance operations. Intensive play, especially in unfavorable weather conditions, causes enormous stress on the vegetation base layer (McCoy and McCoy 2009). This reduces the amount of medium and larger pores and the water capacity (Głąb und Szewczyk 2014; Bunnell et al. 2002). The lack of coarse pores leads to a decrease in rooting depth and an inhomogeneous root growth (Lipiec and Hatano 2003). The decreasing uptake of water and nutrients, impairs the vitality of the grasses. This leads to a higher need for maintenance. A layer of undecomposed organic material, thatch, also has a negative effect on water infiltration (Beard 1973). An important maintenance operation is topdressing with sand to improve the shear strength, the wear resistance and to prevent the formation of thatch (Beard 1973; Kowalewski et al. 2010; Carroll and Petrovic 1991; Trenholm et al. 2000; Mathew et al. 2016). The shear strength and the surface hardness are important to prevent divots and reduce the risk of injury for players (Williams et al. 2013; Powell and Schootman 1992). This is an important quality criterion, especially under humid climate conditions. To reduce the negative effects of usage, it could be necessary to improve the soil physical properties.

Native-soil and sand-based rootzones are predominantly used on sports fields in Germany. The design method depends on the nature of the soil, the location and the intensity of use. Often amateur sports fields are established on native soils (James 2011). The advantage is the low cost, because the existing soil is used as a root zone for nutrient and water supply (Sayers 1995). But in wet locations with loamy soils, there are problems with water permeability, waterlogging, and thus a lack of air supply to the roots (Sports Turf Managers Association und others 2008; James et al. 2007a; Adams 1986). This results in a poor turf quality and a low playability of the sport field. If the water permeability of the topsoil is insufficient, a sand-based rootzone with a minimum thickness of 80 mm can be loosely interlocked with the subsoil, a sufficient water permeability implied (DFB 2017). The subsoil can be improved by cutting drainage slots and filling them with gravel. The drainage slots should be between 40 and 80 mm wide and extend at least 200 mm below the surface integrated (DIN 18035-3 2006). If the water permeability of the subsoil is still too low, it is possible to choose a construction method with a drainage layer and drainage pipes at 5-8 m intervals below the subgrade. The subgrade consists of the existing subsoil. The drainage pipes are surrounded by a drainage pack of gravel that serves as a temporary storage for the drained water and prevents the pipes from clogging with washed-out fines. In this case, the water is led over the drainage layer into collectors and thus the sports field is drained. However, this increases the cost of construction (Mark 2002). The drainage layer has a thickness of 120-150 mm and a water permeability of more than 180 mm/h (DIN 18035-4 2018). The grain size distribution of the installed drainage layer must be between 0.06 and 20 mm. The installed material must not contain any slurry grain so that the drainage holes are not clogged. According to the standard DIN 18035-4, the sand-based rootzone must have a water infiltration rate greater than 60 mm/h and at the same time the layer must have a water capacity greater than 30 % by volume. The recommended particle size distribution must be between 0.02 and 9 mm in diameter, with a maximum of 20 % of the volume having a diameter smaller than 0.06 mm. This particle size distribution results in good water infiltration and a well-aerated root zone layer, providing good growing conditions for the turfgrasses. The minimum thickness of the rootzone layer must be at least 120 mm for constructions with a drainage layer and at least 80 mm without a drainage layer, according to the standard. The installed soccer field should be constructed with a crown arrangement having a slope of 0.5% to 0.8% to the sidelines to ensure good drainage of precipitation water (Kowalewski et al. 2015). Keeping the roughness of the surface as low as possible is important for the playability of the sport field. If the surface profile is uneven, the players can be injured and the desired mowing height cannot be reached (Dixon et al. 2015). In addition, an increased roughness is associated with a decreasing ball roll distance. Roughness is defined by the deviation from the ideal surface of the object (Sayers 1990; Jester and Klik 2005). On sport fields, the roughness is the deviation of the profile from an ideally leveled sport surface. According to the German standard DIN 18035-4, the evenness of a sport field is measured with a 4 m long leveling bar and a measuring wedge with a measurement resolution of 1 mm. The unevenness of the sports field surface must not exceed 20 mm over a length of 4 m (DIN 18035-4 2018). This method is normally used for the construction acceptance of a sport field.

In order to achieve these requirements, the rootzone is usually a mixture of scaffold materials, such as topsoil, sand and lava, to which aggregates, like loam or peat are added (McCoy 1998, 2013; Taylor et al. 1997). Especially the topsoil of a root zone mix must be free of plant parts, such as seeds or roots (DIN 18035-4 2018). Organic components such as peat serve to improve nutrient supply while adjusting water availability (McCoy 2013). Also, studies with biochar show an improvement in water-holding capacity with a simultaneous increase in grass growth in terms of root length and dry matter (Vaughn et al. 2015). In order to obtain sufficient shear strength and water holding capacity of the sand-based rootzone, care should be taken to ensure sufficient grain gradation as well as a stocky, angular grain shape (Bingaman and

Kohnke 1970). The grain surface should be as rough as possible. In particular, the composition of the scaffolding material sand is of great importance. High proportions of fine sand and a wide grain gradation reduce water permeability and increase the tendency of the surface to compact (Li et al. 2009; McNitt and Landschoot 2005). Due to the reduced water permeability, the surface remains moist longer and algae growth and the spread of shallow-rooted, low-shear grass species occur (Baldwin and Whitton 1992; Carroll et al. 2021). The root zone mixture can be installed as a ready-mixed mixture or it can be mixed on site, for example from the topsoil. Especially in the case of on-site mixing, care must be taken to ensure uniform mixing of the components. Compaction by construction machinery has to be avoided during the installation of the sand-based rootzone. This would cause problems during the operation of the sports facility. Rooting is limited to the sand-based rootzone, thereby limits the nutrient and water storage capacity of the turf. This significantly increases the need for fertilizer and irrigation of the turf. However, the standard construction method significantly increases the life span and the playability of the sports field, even under unfavorable weather conditions. Up to 800 h/year of play are possible without causing long-term damage to a sports field (DFB 2017). A sufficient water supply of the turfgrasses is a major challenge for planning and constructing sports fields (Huang and Fry 2008; DIN 18035-4). As a consequence, irrigation is necessary. Unfortunately, intensive and frequent irrigation leads to high water consumption. The average irrigation demand of a sports field in Germany lies between 75 and 250 mm per year, depending on the region (DFB 2011). Daily water consumption of sports fields ranges from 2.5 mm and 7.5 mm (Leinauer et al. 2012). The irrigation season in Germany starts in May and ends in September. High temperatures above 15 degrees increase the water demand in summer up to 8 l/day (DIN 2003; DFB 2017). During the winter, irrigation is usually not necessary, however the higher precipitation must be drained. Due to more frequent drought periods as a result of climate change, irrigation may be prohibited or restricted (Huang 2008; Lund et al. 2018). Therefore, future sports fields will need to have improved water permeability while simultaneously enhancing the water supply to the turfs. Due to the climate change, extreme weather conditions are becoming more frequent, leading to longer periods of drought, or also heavier rainfall (IPCC 2014). This increases the demands on the management and the construction of sports fields. Sports fields using natural turf are important recreational areas. Especially in urban areas, they are very important for the microclimate because they have a high evapotranspiration (Beard and Green 1994). In order to ensure the usability under changing climatic conditions, adaptations of already existing sports fields have to be made and the construction methods of new fields to be built must be changed. There are different options available to adapt water management in particular. For new sports fields to be built, there is the opportunity to increase drought stress tolerance by choosing adapted seed mixtures. Especially red fescue (*Festuca rub*ra L.) has a low evapotranspiration rate compared to, for example, English ryegrass (*Lollium perenne* L.). These cool-season grasses have moderate evapotranspiration rates of 7-8.5 mm/d (Huang and Fry 2008; Beard 1973; Beard and Green 1994) Evapotranspiration also depends on factors that promote evaporation, such as wind, temperature, and humidity. When planning new sports fields it is possible to create a ticker rootzone layer (Maschler et al. 2019). This increases the absolute water retention capacity in the rootzone layer and longer drought periods can be endured. Changing the composition of the root-zone mixture by adding silicates, peat or synthetic materials can also increase the water holding capacity, but larger amounts of these materials can reduce the water infiltration rate (Nus und Brauen 1991; McCoy and McCoy 2009).

To adapt existing sports fields to changing climate conditions it is possible to apply or to incorporate beneficial materials. Applying a layer of material to a turf surface, is called topdressing (Carrow 1979). The goals are to improve water permeability and water retention, to reduce thatch, and to level the surface (Davis 1978; Johnson et al. 2006; Stier und Hollman 2003). Mechanized topdressers have a storage hopper with a conveyor belt at the base to transport the material to the back of the machine (Lettner 1999). Here, the material is uniformly spread by a rotating brush or rotating spreading disks. Larger volumes of the hopper reduce the frequency of refilling, but increase the weight of the filled machine (Lettner 1999). This can cause soil compaction. Sand is the material mostly applied (O'Brien and Hartwiger 2003). It increases the coarse pores at the surface of the turf. Instead of sand, other amendments like peat, compost, superabsorbers or fertilizers can be applied (Johnson et al. 2009; Alec R. Kowalewski et al. 2010; Darini et al. 2015). Using compost for topdressing increases the quality of turfgrass color, growth and foliar nitrogen, due to the fertilization effect (Garling and Boehm 2001). But these methods just apply the material on the surface, no interlocking occurs. To achieve this, it is necessary to open the canopy, penetrate the soil and incorporate the beneficial materials. There are only a few options, belonging primarily to sports turf cultivation practices. For instance, machines that open the turf with punctual or linear penetrating tools and either displace the soil or bring it to the surface. The removed soil can be replaced by other materials or it can be processed and reincorporated into the root zone.

A wide spread mechanical method is hollow tine coring. Typically, the tine diameter is between 6.35 mm and 19.05 mm and the working depth is between 75 mm and 150 mm (Puhalla et al. 2010). According to the working process, these machines are normally used for improving soil gas exchange and breaking up compaction (Murphy et al. 1993; Dunn et al. 1995; Rowland et al. 2009; McCarty et al. 2007). Compared to hollow tine coring, the principle of solid tine coring is to displace the soil during penetration. The advantage is, that the disruption of the surface is limited, when using a solid tine (Murphy et al. 1993). But solid tine coring can cause sidewall compaction and encourage a cultivation pan at the working depth (Malleshaiah et al. 2018). Deep tine coring machines have a greater working depth from 200 mm to 300 mm. Machines with hollow and solid tines are also used. Depending on the machine, the solid tines cause a quaking action in the soil (Puhalla et al. 2010). Deep drilling is another type of mechanic cultivation for sport fields that works in a punctual manner. These machines are used to drill holes into the rootzone layer (Linde et al. 2022). The drills typically have a length of 300 mm and a diameter of 25 mm (Morgan et al. 1965). Depending on the diameter of the drill, the holes are left open, the holes are backfilled with the discharged material or filled with dry sand. Systems like Drill&Fill fill the holes with dry sand in one step (Linde et al. 2022). The sand on the surface is brushed off. Sand slitting is another commonly used mechanical method to improve the drainage capacity of sports fields in the long term. A trencher excavates slit drains, where the soil is removed from the sport field and replaced with sand or gravel (Cereti et al. 2004; James et al. 2007b; Adams 1986). Sand slitting is expensive and causes severe damage to the turfgrass, which then requires a prolonged regeneration period (Kowalewski et al. 2015). Mole drainage is a less expensive installation method to drain sport fields on clayey sites (James et al. 2007c). It is achieved by pulling a bullet-shaped foot through the soil to create a channel at a depth of 400mm (James et al. 2007a). Due to this, the turf cover is less affected.

1.2 Aims and objectives

The aim of this work was to develop a decision model for newly constructed sports fields in order to adapt them to local climatic conditions by customizing the layer-by layer system. For existing sports fields, the aim was to develop and evaluate a technical solution that allows the incorporation of nonwovens into existing vegetation layers of sports fields. In order to accomplish this goal, the following objectives should be accomplished:

- The Decision Support model must improve the economic efficiency based on water costs
- The nonwovens must be incorporated vertically and the working depth must not exceed ± 20 mm.
- The tractive force requirement of the device should be kept low, so that it can be attached to low-powered towing vehicles.
- The weight of the device must be reduced, so that the three-point linkage can carry it.
- The ground cover of the turf may not be reduced by the incorporation.
- The overall length of the device has to be short in order to keep the turning area as small as possible.
- The surface has to be recompacted in order to restore evenness and connect the nonwoven to the pores of the rootzone and the drainage layer.
- The surface roughness of the sports field must not increase after the installation of the nonwovens, regardless of the measurement method used to describe the roughness.

1.3 Appended papers

The dissertation is based on the following three papers:

A. Maschler, T.; Stürmer-Stephan, B.; Morhard, J.; Stegmaier, T.; Tilebein, M.; Griepentrog, H. W. (2019): A decision support method for designing vegetation layers with minimised irrigation need. In: Annals of Operations Research, pp. 1–24. https://doi.org/10.1007/s10479-019-03401-0
B. Stürmer-Stephan, Bastian; Morhard, Jörg; Griepentrog, Hans W. (2021): Development and evaluation of a device to incorporate biodegradable textiles into sports turfs.
   In: Landtechnik, Bd. 76 Nr. 2. https://doi.org/10.15150/lt.2021.3267
C. Stürmer-Stephan, Bastian; Morhard, Jörg; Griepentrog, Hans W. (2022): The Impact of Incorporated Nonwovens on the Surface Roughness of Sport Pitches. In: Applied Sciences 12 (6), S. 2966. https://doi.org/10.3390/app12062966

The theorical approach to improve a sports field before the construction by modelling with a user-friendly calculating tool was presented in paper A. The developed method uses meteorological weather data, hydrological models and the properties of the rootzone for calculating the economically best layer design. In paper B, a device was developed to incorporate a biodegradable nonwoven into an existing sports field. The device was evaluated in terms of the accuracy of the device working depth, the recompaction after the incorporation of the nonwoven and the impact of the device to the turf. In Paper C a measurement frame, with an ultrasonic sensor, a laser and a feeler wheel were developed. The different sensors were evaluated and the impact of the incorporation of a nonwoven to different Roughness parameters was measured.

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2 A decision support method for designing vegetation layers with minimised irrigation need[1]

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Abstract

Selecting a vegetation layer design goes along with determining its future irrigation need. Therefore, it is essential to take a design decision that is minimising the cumulated con- struction and irrigation costs in a given depreciation period. This contribution showcases a decision support approach using long term weathering time series and soil water balances with example data for turf soccer fields in six German regions. The approach relies on minimising both material and irrigation costs by modifying soil layer design parameters; here the layer thickness and therefore its water retention capacity. E.g. suggested layer thick- nesses between 200 and 250 mm for Stuttgart lead over 10–40 year depreciation periods to estimated substrate and water cost savings between 90 and 194% in comparison to a standard substrate layer thickness of 80 mm. For practical applications, the presented theoretical approach needs to be adapted with the usable soil water storage capacity and relationships describing evapotranspiration for given substrate-turfgrass combinations.

Keywords: decision support method, soccer field design, substrate layer, simulation-based optimisation, metaheuristic optimization

[1]Maschler, T.; Stürmer-Stephan, B.; Morhard, J.; Stegmaier, T.; Tilebein, M.; Griepentrog, H. W. (2019): A decision support method for designing vegetation layers with minimised irrigation need. In: Annals of Operations Research, pp. 1–24.

2.1 Introduction

2.1.1 Problem statement

The consortium of the German research and development project RasenTex (Kaya et al. 2017) develops a novel modular design model for vegetation layers for turfgrass like on soccer fields or e.g. in parks with enhanced water permeability and storage capacity. The motivation is a market gap for economical vegetation layers with both minimised irrigation need and excellent percolation. The design model relies on regionally available substrate components and specially designed textile structures with optimised capillary properties.[1] Besides increasing the annual soccer field usage time, one major objective is to reduce irrigation need (Klapproth 2017) and therefore maintenance costs.

For vegetation layers, there are usually different technical design models available. Evapotranspiration of the vegetation layer and local weather conditions should be considered as well for designing the vegetation layer's water storage capacity. An interesting up to now intensely discussed, but not commercially addressed recurring cost block forms the influence of local weathering on maintenance costs.

Vegetation layer planning and construction companies do choose technical design models for projects in function of compliance to the required qualitative features and costs. Besides choosing the most cost effective vegetation layer design model, planning and construction companies configure it in such manner that both its construction and recurring (here irrigation) costs are minimised while preserving the design model's qualitative features. Unfortunately, there is no method available for adapting vegetation model design parameters in function of construction and recurring costs like irrigation, so far.

2.1.2 Objectives

Companies designing and planning gardens, landscapes like parks as well as sport grounds need to be able to discuss, offer and select the best layer structure and to find optimal layer thicknesses with minimised substrate and irrigation costs in terms of local long-term weathering conditions.

This contribution showcases a metaheuristic optimisation approach for parameters in given vegetation layer design models in terms of long-term weathering, construction and irrigation costs by the example of small to medium sized soccer club fields in different moist and drier regions of Germany.

[1] Textile structures do feature capillary properties that may complement those of vegetation layers: e.g. adsorption volumina of 100–1000 mass% or capillary rise levels up to 50 cm and more with comparatively high hydraulic conductivity values are common material properties for nonwovens designed as fluid absorbers (Maschler et al. 2016). Hence, these materials do form interesting aggregates for soil substrates, as their hydraulic conductivity is much higher than in soil substrates (Kaya et al. 2017).

2.1.3 Overview

This work is structured as follows. The presentation of the foundations in Sect. 2 starts an overview of commonly used design models for soccer fields in Germany. Then, a suitable evapotranspiration model and time series are chosen. Following, the soil water balance, economical assessment criteria as well as the optimisation approach are described. Section 3 describes the chosen approach. After some general specifications, a stock-flow model for the water balance in vegetation layer substrates is presented. Then, the cost assessment model for a simulation run is presented, followed by the optimisation approach and the presentation of exemplary results. The concluding discussion of the results in Sect. 4 shows points of improvement for the modelling approach and features potentially interesting aspects for key stakeholder groups. Section 5 summarises the conclusions.

2.2 Foundations

2.2.1 Technical design models for soccer fields in Germany

The following standardised technical design models are available (Schlesiger et al. 2017)[2]:

- DIN 18035-4:2012-02: Sports Ground—Part 4: Sports turf areas (2012).
- RAL GZ 515/2 Factory-produced turf soils […] for sports grounds (2013).

The USGA recommendations for golf courses are occasionally in use as design model, as well.[3]

The German Football Association (Deutscher Fußballbund, DFB) recommends a substrate layer thickness of 80 mm without, and 120–150 mm with a drainage layer, below.[4] RAL-GZ515-2 (2013) relies on a substrate layer thickness of 120 mm with a drainage layer, below. Both standards rely on special grading curves to assure a sufficient water permeability as well as adequate capillary moisture storage. As both approaches are rather costly for small soccer clubs, sports field constructors do offer these clubs individualised solutions, using e.g. quartz sand and local topsoil, adapting sometimes the design guidelines for golf courses using e.g. USGA (2017) or the German standard FLL (2008) with 300 mm substrate layer thickness.

The vegetation layer design models in RasenTex (Kaya et al. 2017) follow the recommendations in DIN 18035-4:2012-02, but do explicitly use locally available soil components and a layer system that is adapted to local weathering. This may result in substantial economical savings by designing e.g. the layer thickness just as high as necessary or by mixing the substrate components on site using locally available materials.

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[2] p. 92 gives further specific construction and irrigation recommendations.
[3] O’Brien and Oatis (2018), USGA (2017).
[4] Schlesiger et al. (2017).

Soil water storage capacity in sports ground substrate layers is in general bigger than in the locally available soil, as components with medium coarse, voluminous pores between the grains (e.g. sands) and pores inside the material (e.g. some lava types, expanded clay) are being used. Typical values for soil water storage capacity for turfgrass substrate layers are between 10 and 20 % water mass per substrate mass; USGA recommends substrates[5] with water storage capacities between 15 and 25 %.

In general, available soil water is estimated as the difference between field capacity[6] as an upper limit for water available for plants and remaining soil water at the permanent wilting point. However Schlesiger et al. (2017) recommend irrigating when wilting starts, thus e.g. reducing susceptibility to infections. Therefore, slightly reduced values for the relative soil water storage capacity will be used, here. These will be called "*usable soil water storage capacity*".

In order to ensure playability on the sports ground after heavy rainfall, the soil under the vegetation layer should have better drainage capabilities than the vegetation layer. If necessary, a dedicated drainage layer is placed under the vegetation layer. This implies that there is a capillary break below the vegetation layer.

2.2.2 Modelling evapotranspiration

Zhao-Liang et al. (2009) describe evapotranspiration as "the loss of water from the Earth's surface to the atmosphere by the combined processes of evaporation from the open water bodies, bare soil and plant surfaces, etc. and transpiration from vegetation or any other moisture-containing living surface". Kaicun and Dickinson (2012) provide a review on the subject. The evaporation models being most popular in Germany form the Penman-Monteith model (Monteith 1965; Penman 1948 and Wallach et al. 2014) and the model of Haude (1954). However, the German standard for irrigating sportsgrounds DIN 18035- 2:2003-07 (2003) relies on a simple approach by calculating daily evapotranspiration in function of the day's highest temperature value. As this approach is inferior to the Haude model, it is discarded, here. The Haude model covers potential evapotranspiration, only, whereas the approach of Penman–Monteith can be adapted to cover real evapotranspiration, as well, by taking available soil water into account. The Penman–Monteith model is the most recommended one, but needs more input data and calculation effort. The Climate Data Center (CDC) of Deutscher Wetterdienst provides for many localities in Germany weathering time series with daily resolution.[7] For selected weather stations,[8] CDC provides calculated daily values of

[5] For optimal substrate mixtures, see e.g. Yin et al (2012).
[6] See e.g. Zotarelli et al (2010).
[7] See https://www.dwd.de/DE/leistungen/cdcftp/cdcftp.html; accessed on 09 March 2018.
[8] See ftp://ftp-cdc.dwd.de/pub/CDC/derived_germany/soil/daily/recent/derived_germany_soil_daily_recent_stations_list.txt; accessed on 09 March 2018.

the real and potential evapotranspiration over grass and sandy loam[9] using the AMBAV model of Löpmeier (2014) an adapted version of the Penman-Monteith model and the potential evapotranspiration following the Haude model.

The following requirements do apply when selecting an evapotranspiration model for turfgrass on soccer playgrounds:

a) Soccer playgrounds are irrigated and fertilised for providing optimal playing conditions.
b) The usable water storage capacity by the local turfgrass on the substrate layer is not known.
c) There is often a drainage layer under the substrate layer.

Constraint (a) implies that an evapotranspiration model with potential evapotranspiration should be chosen, as there is always sufficient water available. (b) could be overcome by capturing time series of evapotranspiration and local weathering of the artificial vegetation layer and estimating the usable water storage capacity. This permits as well building a regression model for evapotranspiration. Restriction (c) is limiting the substrate layer's capillary water storage capacity by introducing a capillary break towards the subsoil. If no real overgrown substrate layer-specific evapotranspiration time series are available, it is suitable to choose an evapotranspiration time series representing potential evapotranspiration. Figure 2-1 shows an exemplary plot of two estimated potential evapotranspiration time series over the estimated real evapotranspiration.[10] It can be seen that the estimated time series for potential evapotranspiration over grass and sandy loam (AMBAV) VGSL does always scatter above the corresponding real evapotranspiration value, as it does not take stored water in the ground into account. The estimated time series for potential evapotranspiration over Grass (Haude). CPGH is sometimes underestimating real and potential evapotranspiration. For the purpose in this work, the estimated time series for potential evapotranspiration over grass and sandy loam (AMBAV) VGSL according to Löpmeier (2014) from CDC are chosen, as their values can be seen as upper borders for real evapotranspiration on irrigated and fertilised soccer playgrounds. Hence, vegetation layer design optimisation will be carried out implying inferior conditions as in real world. This will lead to slightly more conservative design parameters "on the safe side" than actually necessary.

2.2.3 Soil water balance

Soil water balances are well-described and easy to integrate in simulation models (see e.g. Wallach et al. 2014). Typical modelling components form:

[9] See ftp://ftp-cdc.dwd.de/pub/CDC/derived_germany/soil/daily/recent/DESCRIPTION_derivgermany_soil_daily_recent_en.pdf; accessed on 09 March 2018.
[10] The time series is for Bernburg/Saale, CDC station index 445, 84 m above mean sea level, latitude 51.82°, longitude 11.71° in Saxony-Anhalt, from 31/03/2017 to 30/09/2017.

(a) The dependency between evapotranspiration and the capillary stored water quantity.

(b) The relations between infiltration, capillary stored water quantity and deep perlocation.

The substrates to be used are individually composed and sowed with locally adapted turfgrass and kept in intensive culture with irrigation and fertilisation. Quantifying the functional dependencies in (a) is important, as the usable soil water storage capacity is usually a nonlinear function of the layer thickness. As vegetation layers are usually designed with locally available components, each one has its own functional dependencies.

Irrigating sports fields is necessary in longer dry periods during the main season. It forms therefore a major input to soil water. Schlesiger et al. (2017) do recommend irrigation intervals of 5–8 days and to detect the irrigation need by observing whether wilting starts. The total irrigation quantity should be between 20 and 25 l/m^2 for soccer playgrounds with a drainage layer, with a maximum hourly quantity of 5 $l/m^2/h$.

2.2.4 Economical assessment

Park, garden and sports facility planning, design and construction companies need to be capable to offer their customers best value for money. Value is usually pleasure in playing, depending on a number of qualitative factors. There are usually two types of costs in facility planning: non-recurring construction and recurring maintenance costs. The following subsections explain these cost categories for turfgrass soccer playgrounds.

2.2.4.1 Construction costs

Construction work should be carried out with the most suitable materials and least effort as well as material usage. A major cost item when constructing sports grounds do form the materials for the substrate layer. The mixing process for the substrate can be carried out off-site at a quarry or at a compounding plant or on-site, e.g. with a wheel loader. The mixing recipe is usually defined and optimised, before construction starts. Hence, the material properties and especially the usable water storage capacity are analysed, beforehand. In Germany, e.g. sands do usually cost 8–18 €/t free site; special substrates with higher water storage capacity cost between 20 and 100 €/t free site. Costs for special substrates can be reduced significantly by mixing them on-site, as transport costs for lightweight porous materials like lava and expanded clay are lower and freely available local topsoil can be used.

Material usage related construction labour and machinery costs do usually make up a much smaller share of material costs. They cover dredging and relocating the present soil, as well as transport, mixing and installation costs for the new substrate. As they are roughly proportional to the total substrate quantity, they can be combined with the material costs. Hence in this work, the substrate costs comprise both the material, machinery and labour costs. The substrate costs are relative to the necessary substrate quantity [€/t]:

$$Relative\ Substrate\ Costs = \frac{Material\ Costs + Machinery\ and\ Labour\ Costs}{Substrate\ Quantity} \quad (1)$$

Depreciation costs form an economic approach for relating the one-off construction costs to costs per time period. Here, depreciation costs will be used to spread the construction costs over the usual usage time, leading to an annual "rent" for the sports ground. The usual usage time of sports grounds does vary considerably: Turfgrass on sportsgrounds in stadiums of soccer clubs the Germany's first federal league is often replaced twice a year because of special conditions, e.g. few light and wind as well as alternative forms of stadium usage, like e.g. rock concerts. Well-designed turfgrass sportsgrounds do have under correct course maintenance, usage and natural environmental conditions a life time that is only restricted by the lifetime of its technical components, like drainage tubes. Here, life times of 20–40 a are expected.

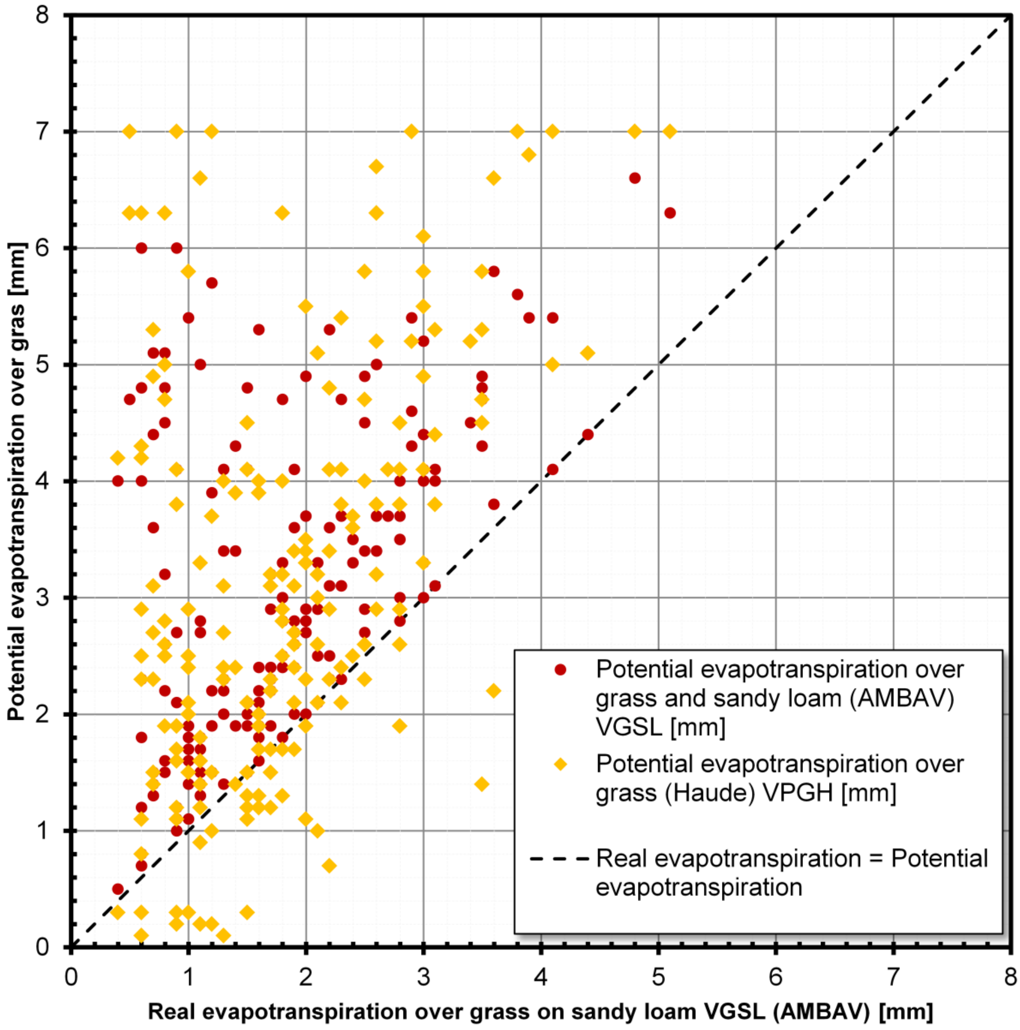

Figure 2-1: Estimated potential over real evapotranspiration plot, for Bernburg/Saale.

[a] See footnote 9 for the weather station information.

2.2.4.2 Maintenance costs

Turfgrass sportsground maintenance costs including e.g. mowing, scarifying, fertilising, sanding and rolling as well as irrigating do make up about 30 €/m²/a in Germany. One component of the maintenance costs—the irrigation costs—is principally reducible by design: providing more usable soil water storage capacity should help the turfgrass overcoming longer dry periods. According to DEStatis (2018), tap water costs about 2.00 €/m³ in Germany, excluding sewage system costs. Therefore, minimising irrigation by design forms a well approach for saving costs.

2.2.5 Optimisation approaches

2.2.5.1 Cost function

Optimisation objective is to find a cost minimum for the sum of a depreciation-based share of the substrate costs and the irrigation costs for given evapotranspiration and precipitation time series, the overall annual costs. Irrigation costs are calculated by cumulating irrigation quantity over the simulation time period. The substrate costs can be varied by adapting the usable soil water storage capacity and therefore the substrate layer thickness forming the vegetation layer. The turfgrass root depth does give a minimum limit for the substrate layer thickness.

$$Overall\ annual\ Costs = \frac{Irrigation\ Costs}{Simulation\ Duration} + \frac{Substrate\ Costs}{Depreciation\ Period} \quad (2)$$

With:

$$Substrate\ Costs = Relative\ Substrate\ Costs \cdot Layer\ Thickness \quad (3)$$

The cost function – the overall annual costs – does only depend on one continuous variable: the layer thickness. The overall annual costs are calculated after simulation runs. As irrigation events will be set and quantified by an algorithm during simulation[11], the cost function can be assumed to be non-continuous, probably with a couple of local minima. Hence, a metaheuristic optimisation approach should be chosen (see e.g. the surveys of Bianchi et al 2009 or Boussaïd et al 2013).

2.2.5.2 Optimisation approach

Figure 2-2 shows a typical generic simulation-run based optimisation approach, mainly applied in non-linear programming with secondary condititons.

[11] Equations (5) and (6) in Table 2-2

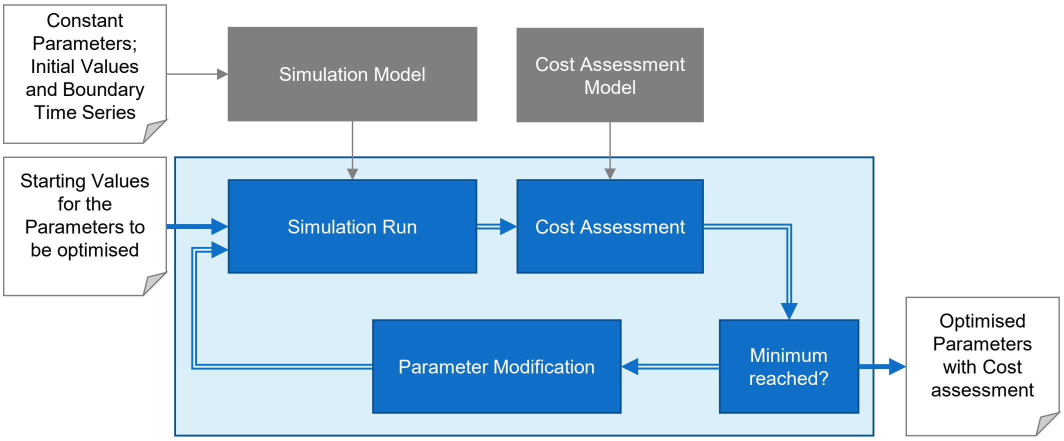

Figure 2-2: Simulation-run based optimisation approach

An optimisation task does basically have the following processing steps: The simulation model is preconfigured with constant parameters, initial values for the stocks and boundary time series. For given starting values and validity ranges for the parameters to be modified, the following loop is carried out by the optimisation routine: a simulation run of the chosen simulation model is executed. Then, a cost assessment by applying the cost function on the results of the simulation run is carried out, using the corresponding cost assessment model. In case that a global cost minimum in the search space for the parameters to be optimised is detected, the loop stops. Else, the optimisation routine carries out a modification of the parameters to be optimised and starts another simulation run.

2.3 Modelling approach

2.3.1 General specifications

A simulation run covers n discrete time steps $t_i = [0,1, \dots, t_i, \dots, t_n]$ with $t_i \in \mathbb{N}_0^+$ and the time increment $\Delta t = 1$ d. The current time step in a simulation run is available in the variable “time”[12].

2.3.2 Stock-flow model for water balance of vegetation layer substrates

A simple linear soil balance model will be used, here, because:

- The main objective of this work is to showcase the methodology.
- Metaheuristic optimisation approaches do mainly rely on many model executions.
- Both excellent water infiltration[13] and high field capacity do form core properties of turfgrass substrate for soccer fields. However, the available precipitation and evapotranspiration input time series do only provide daily cumulated values for precipitation.

[12] The authors forego listing the usage of time in the stock-flow models for reasons of simplicity.
[13] Typically ≥ 60 mm/h according to DIN 18035-4:2012-02, p.10, Table 3.

Therefore, the relations (b) will be modelled as simple balance equations, but with a maximum usable capillary storage capacity. Figure 2-3 presents the dependencies for simulation-based calculations of the cumulated irrigation quantity for given constants and boundary input values and a value for the usable soil water storage capacity. The notation applied in the model forms the System Dynamics stock-flow notation[14].

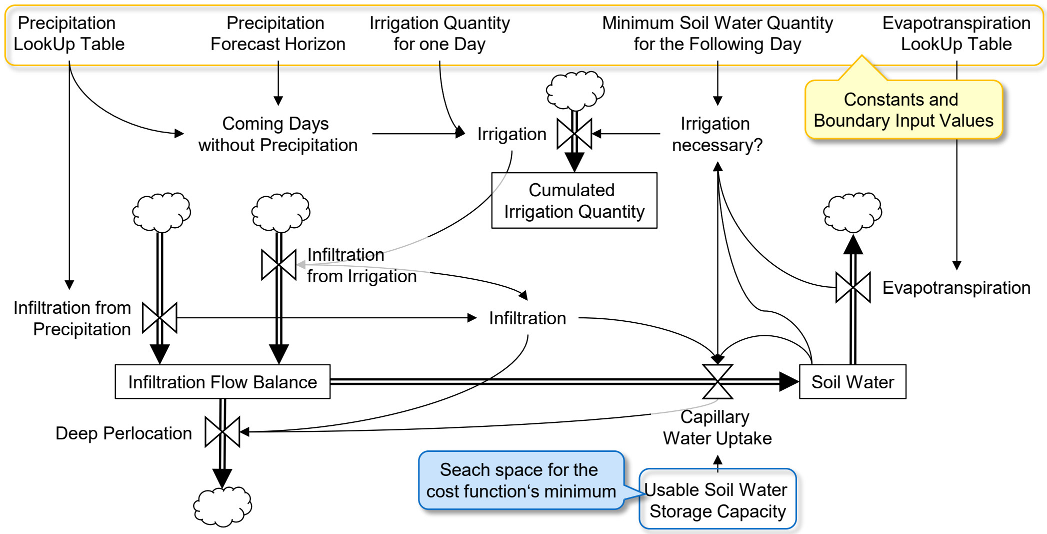

Figure 2-3: Stock-flow model of the water balance in a vegetation layer substrate.

The values of stocks (generalised below as) x_i refer always to a given time point i. Here, the values of the flows Δx_i refer to the change in quantity between the time points $i-1$ and i. The current value of a stock x_i at the time point i is calculated by summating the flow balance Δx_i of the current time point i to the stock value x_{i-1} at the last time point[15]:

$$x_i = \max(x_{i-1} + \Delta x_i \cdot \Delta t; 0) \qquad (4)$$

Table 2-1 describes the constants and boundary input values in Fig. 2-3. The provided sample values could correspond to a sandy substrate with a share of local soil, mixed on-site. The last constant in Table 2-1 needs to be varied when searching for the cost minimum.

[14]The main modelling entities do form stocks (state variables, boxed) that are connected with flows (double-lined arrows with valve symbols), representing their rates of change. Auxiliary variables (start and end points single-lined input/information arrows) are used to calculate dependent values, whereas constants and lookup tables provide fixed scalar and vectorial data (starting point for input arrows). Sources and drains do represent state variables with an arbitrary, infinite value (represented as cloud symbols). Stock-flow models can be mapped directly on nonlinear differential equation systems. See e.g. Sterman (2001, 2002a, b).

[15] The $\max(a_1; \ldots; a_i; \ldots; a_n)$ function returns the biggest of its arguments a_i. Here, its role in (4) forms restricting x_i to $x_i \in \mathbb{R}_0^+$.

Table 2-2 describes the auxiliary variables in Fig. 2-3. Table 2-3 features the flows in Fig. 2-3. The used assignment for calculating the irrigation quantity IRR is quite simple: although precipitation forecasts are quite reliable in terms of their start and duration for broader areas, precipitation quantities may vary, locally. Therefore, a simple approach basing on counting the coming dry days was chosen, here.

Table 2-1: Constants and boundary input values in Fig. 2-3

Name	Symbol	Value Type	Sample Value	Unit
Precipitation LookUp Table[a]	PLT	Vector with n elements $\in \mathbb{R}_0^+$	$[0; 12.2.0; \ldots 5.2]$	l/m²/d
Evapotranspiration LookUp Table[b]	ELT	Vector with n elements $\in \mathbb{R}_0^+$	$[1.5; 3.0; \ldots 7.0]$	l/m²/d
Precipitation Forecast Horizon	PFH	$\mathbb{R}_0^+$	4.0	d
Irrigation Quantity for one Day	IQD	$\mathbb{R}_0^+$	5.0	l/m²/d
Minimum Soil Water Quantity for the Following Day[c]	MWQ	$\mathbb{R}_0^+$	5.0	l/m²/d
Usable Soil Water Storage Capacity[d]	SWC	$\mathbb{R}_0^+$	12.0	l/m²

[a] time series, obtained from CDC. The unit l/m² is equivalent to mm.
[b] Ibidem.
[c] So that the turfgrass might start wilting, slightly.
[d] This constant is vegetation and substrate dependent; it represents how much consumable water in the soil is available to the plants under a specified care programme. The value varies with the substrate layer thickness and needs to be characterised, individually.

Table 2-4 lists the stocks in the model together with their flow balances.

2.3.3 Assessing costs of simulation runs

After running simulations, the total costs for the current model configuration are calculated. This is carried out in function of the cumulated irrigation quantity *CIQ (l/m²)* and the usable soil water storage capacity *SWC (l/m²).* The substrate layer thickness is calculated, additionally, for easier comparisons with other soccer playground design models. Figure 2-4 shows the stock-flow model for the economical assessment of a simulation run.

The overall annual costs do form the sum of the depreciation costs for the substrate and the mean annual irrigation costs. Tables 2-5 and 2-6 do list the constants and auxiliary variables in Fig. 2-4.

The minimum layer thickness *LTmin* = 80 mm in Sect. 2.1 forms as well the lower border of the search space the usable soil water storage capacity *SWC*. The following equations calculate its lower border *SWCmin*, using dependencies (20) and (21) in Table 6:

$$SWC_{min} = \frac{LT_{min}}{1{,}000} \cdot \frac{VSP}{WSCC} \qquad (5)$$

Inserting equation (19) for the volumetric substrate price *VSP* and equation (18) for the water storage capacity costs *WSCC* into equation (24) leads to the following relation[16] for SWC_{min}:

$$SWC_{min} = LT_{min} \cdot SID \cdot SWSC \qquad (6)$$

A rule of thumb is that the rooting depth of periodically cut turfgrass follows the cutting thickness. In case that turfgrass growth tests on the substrate show a lower rooting depth, *LTmin* can be adapted. The maximum layer thickness *LTmax* or usable water storage capacity *SWCmax* should be set intuitively experience-based: optimisation runs with a too low value will result in the given maximum value as an “optimal” one. Clearly too high values will lead to increased computation times, as the search space is much wider than necessary.

[16] Unit conversion: mm$\cdot \frac{\text{t}}{\text{m}^3} \cdot \frac{1\ \text{m}^3_{\text{H}_2\text{O}}}{\text{t}} = \frac{\text{m}}{1{,}000} \cdot \frac{\text{t}}{\text{m}^3} \cdot \frac{1{,}000\ \text{l}}{\text{t}} = \frac{\text{l}}{\text{m}^2}$

Table 2-2: Auxiliary variables in Fig. 2-3

Name	Symbol	Assignment		Unit
Coming Days without Precitipation[a]	$DWOP$	$= \sum_{n:=time+1}^{time+\text{PFH}} \begin{cases} \text{LookUp}(PLT, n) \equiv 0 & 1 \\ \text{else} & 0 \end{cases}$	(7)	d
Irrigation necessary?[b]	$IR?$	$= \begin{cases} SW_{i-1} + IFP_i - ET_i < MWQ & 1 \\ \text{else} & 0 \end{cases}$	(8)	–
Infiltration	INF	$= IFP + IFI$	(9)	l/m²/d

[a] The LookUp(vector, index) function returns the value of the element at the position index in vector.
[b] . In the constraint of this conditional statement, an advance calculation of the soil water value SW_{i+1} for the coming day is carried out using SW_i, CWU_i and ET_i. SW_{i+1} is compared to the minimum soil water quantity for the following day MWQ.

Table 2-3: Flows in Figure 2-3

Name	Symbol	Assignment		Unit
Irrigation	IRR	$= IR? \cdot IQD \cdot DWOP$	(10)	l/m²/d
Infiltration from Precipitation	IFP	$= LookUp(PLT; time)$	(11)	l/m²/d
Infiltration from Irrigation	IFI	$= IRR$	(12)	l/m²/d
Capillary Water Uptake	CWU	$= \min(SWC - SW; INF)$	(13)	l/m²/d
Evapotranspiration	ET	$= LookUp(ELT; time)$	(14)	l/m²/d
Deep Perlocation	DP	$= INF - CWU$	(15)	l/m²/d

Table 2-4: Stocks in Figure 2-3 with flow balance equations

Name	Symbol	Assignment		Initial Value	Unit
Infiltration Flow Balance[a]	IFB	$\Delta IFB = +IFP + IFI - DP - CWU$	(16)	0	l/m²
Soil Water[b]	SW	$\Delta SW = +CWU - ET$	(17)	e.g. $SWC/2$	l/m²
Cumulated Irrigation Quantity[c]	CIQ	$\Delta CIQ = +IRR$	(18)	0	l/m²

[a] The soil water balance was split here in the Infiltration Flow Balance and the Soil Water stock. The latter is fed by capillary water uptake, only. As any water that is not stored in the soil's capillaries goes into Deep Perlocation, the Infiltration Flow Balance stays zero, always.
[b] As the initial value for this stock is unknown, it is estimated as half of the soil water capacity. Resulting errors are negligible, as $SWC \ll \sum_{i=0}^{n} ET_i$.

[c] This stock was introduced for calculating the total irrigation costs after a simulation is finished.

2.3.4 Optimisation approach

In order to reduce construction costs, the design of the vegetation layer was optimized with respect to the boundary conditions maximum layer thickness and water storage capacity.

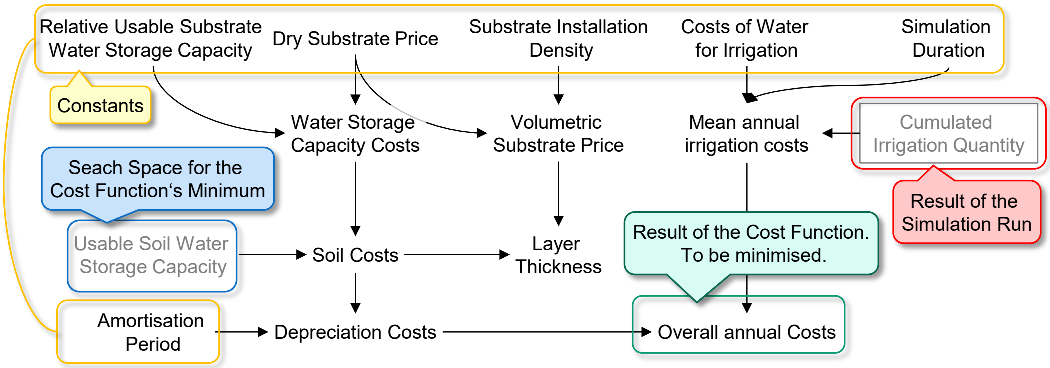

Figure 2-4: Stock-flow model for the economical assessment of a simulation run[a]

[a] Modelling entities already defined in the stock-flow model in the stock-flow model in Fig. 2-3 are set in grey).

Table 2-5: Constants in Fig.4

Name	Symbol	Value Type	Sample Value	Unit
Relative Usable Substrate Water Storage Capacity[a]	$SWSC$	$\mathbb{R}_0^+ \cap [0..1]$	0.12	100%
Dry Substrate Price	DSP	$\mathbb{R}_0^+$	18.00	€/t
Substrate Installation Density[b]	SID	$\mathbb{R}_0^+$	1.4	t/m³
Costs of Water for Irrigation	CWI	$\mathbb{R}_0^+$	2.00	€/m³
Simulation Duration[c]	SD	$\mathbb{R}_0^+$	1	a
Depreciation Period	AP	$\mathbb{R}_0^+$	30	a

[a] The value is a mass percentage with the unit m³ Water/t dry substrate = %; the multiplication factor 100 in the Unit column compensates the percentage fraction of $1/100$.

[b] In installed conditions.

[c] Overall length of the time series taken as a basis.

Table 2-6: Auxiliary variables for the economical assessment of a simulation run

Name	Symbol	Assignment		Unit
Mean annual Irrigation Costs	$MAIC$	$= \frac{CIQ}{1{,}000} \cdot \frac{CWI}{SD}$	(19)	€/m²/a
Water Storage Capacity Costs[a]	$WSCC$	$= \frac{DSP}{SWSC \cdot 1{,}000}$	(20)	€/(l/m²)/m²
Volumetric Substrate Price	VSP	$= DSP \cdot SID$	(21)	€/m³
Soil Costs	SC	$= WSCC \cdot SWC$	(22)	€/m²
Layer Thickness	LT	$= \frac{SC}{VSP} \cdot 1{,}000$	(23)	Mm
Depreciation Costs	DC	$= \frac{SC}{AP}$	(24)	€/m²/a
Overall annual Costs	OAC	$= MAIC + DC$	(25)	€/m²/a

[a] Unit conversion using $1\ \text{m}^3_{\text{H}_2\text{O}} = 1{,}000$ l and the expansion term $1 = \frac{\text{m}^2}{\text{m}^2} : \frac{€}{\text{t}} \cdot \frac{\text{t}}{1{,}000\ \text{l}} \cdot \frac{\text{m}^2}{\text{m}^2} = \frac{1}{1000} \cdot \frac{€}{(\text{l/m}^2) \cdot \text{m}^2}$.

The model in Sects. 3.2 and 3.3 was programmed in Microsoft Excel ® 2010.[17] Excel was used because it's the most common and widespread program for practical applicants. For minimising the Overall Annual Costs in function of the Usable Soil Water Storage Capacity, the optimisation algorithm of the Evolutionary Solver of the Microsoft Excel® Solver Add-In was used. The evolutionary algorithm was used, because it allowed an improved optimization compared to the non-linear GRG.

2.4 Results

After demonstrating the optimisation approach for one season at one location, optimisation results for six locations with typical local weathering in Germany using time series covering 25 a are shown. Then, a sensitivity analysis for the overall annual costs in function of the length of the depreciation period and the substrate layer thickness is carried out.

2.4.1 Time series for one season

The first example features the soil water balance for a turfgrass sportsground nearby Stuttgart airport[18] during the main season 2017 for a soil water storage capacity of 25 l/m², corresponding to a substrate layer thickness of 148.8 mm. The cumulated potential evapotranspiration over grass and sandy loam in the season is 592.0

[17] There are quite better software environment choices for implementing the simulation and the cost model,as input and output data, the models and its documentation should be maintained, separately especially in Decision Support Systems. Here, Microsoft Excel® 2010 was chosen to keep the barriers to entry on a simplelevel for planners and designers.

[18] The CDC weather station identifier is 4931, Stuttgart-Echterdingen, latitude 48.69 °, longitude 9.22 °. The values of VPGB and RSK between 01/04/2017-30/09/2017 were used.

l/m²/season, whereas precipitation amounts to 466.3 l/m²/season. The used parameterisation is the one indicated in Table 2-1 and Table 2-5.

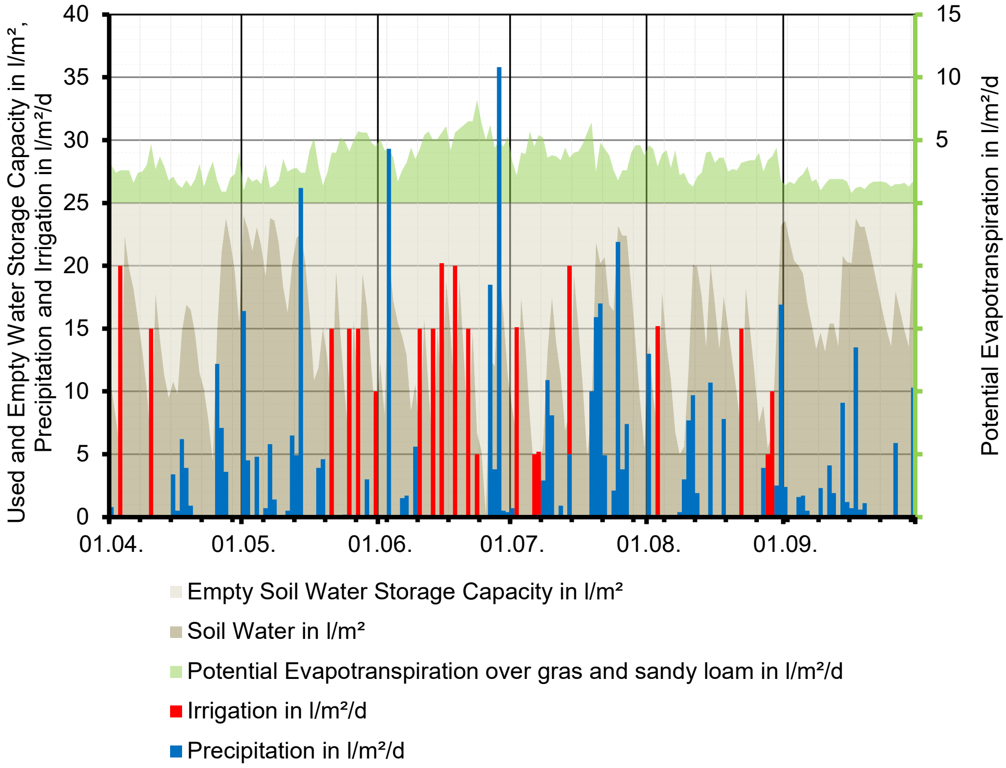

Figure 2-5: Simulated Soil Water Balance on a Turfgrass Soccer Playground in Stuttgart-Echterdingen in the main season 2017, with a Soil Water Storage Capacity of 25 l/m², without Optimisation.

Using the formulas in Sec. 3.2, 20 irrigation events with a cumulated irrigation quantity of 265.0 l/m² are happening in the simulated season. Figure 2-5 shows the corresponding time time series, with longer irrigation periods at the end of May and in June. The estimated overall annual costs with this configuration are 0.655 €/m²/a.

Figure 2-6 shows same the simulated soil water balance – but with an optimised usable soil water storage capacity, using the EA algorithm of the Excel® solver: The soil water storage capacity got increased to 50.1 l/m², whereas the overall annual costs got reduced to 0.541 €/m²/a. The number of irrigation events got reduced to eleven with a total quantity of 145 l/m². The overall annual costs are reduced by 17.4 % to 0.541 €/m²/a, although the substrate layer thickness gets rather doubled. Substrates with an improved water storage capacity could lead to a reduced suggested soil layer thickness, here. It can be seen that only about 40 % of the available spoil water storage capacity are getting replenished by irrigation. The huge soil water storage capacity of

50.1 l/m² is used now to store precipitation in longer wet periods in order to overcome drier periods, better. Hence, less water is lost via deep perlocation.

Table 2-7 compares the optimisation results after applying the two principally eligible Excel® solver algorithms: The evolutionary algorithm performs much better, as the cost function is a non-continuous one because of the algorithm-triggered irrigation events.

2.4.2 Time series covering multiple seasons

Weathering conditions tend to vary locally and annually, considerably. Hence, time series covering local weathering during multiple seasons should be used as a basis for optimising usable soil water storage capacity.

Tables 2-8 and 2-9 compare long-term optimisation runs[19] for six weather stations in Germany, chosen for their specific local weathering conditions. Optimisations were carried out with depreciation periods of 10 and 30 years. As before, the used parameterisation is the one indicated in Tables 1 and 5. For each location, the following tasks were carried out[20]: first, the costs were calculated for a depreciation period of 10 a and a standard soil layer thickness of 120 mm for designs with a drainage layer (see Sect. 2.2.1). Then, the optimisation was carried out. Finally, the depreciation period was increased to 30 a and again, an optimisation was carried out. Without optimisation, the model calculates for the 10 a depreciation period over all annual costs or all locations between 0.554 €/m^2/a for the cool and mostly wet town Garmisch-Partenkirchen and 1.090 €/m^2/a for the dry region around Manschnow, nearby

[19] All time series cover 25 a with in total 9497 values from 01/01/1992 to 31/12/2017.
[20] The results of each task are listed in their corresponding results column.

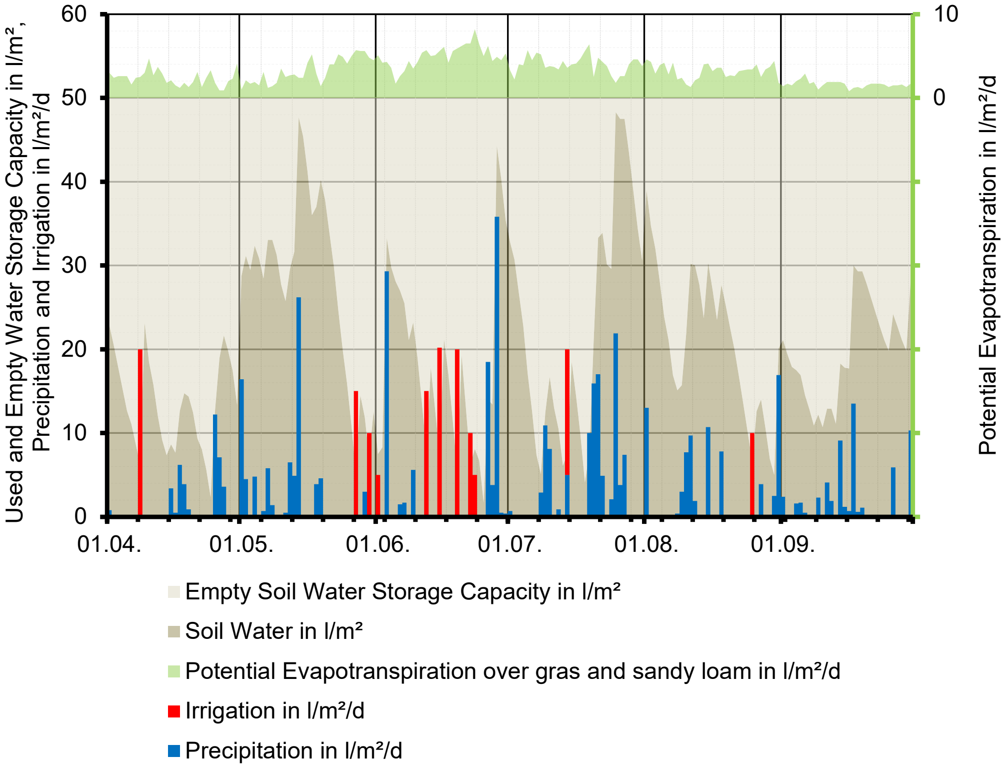

Figure 2-6: Simulated soil water balance on a turfgrass soccer playground in Stuttgart-Echterdingen in the main season 2017 with a soil water storage capacity of 50.1 l/m², after optimization.

Table 2-7: Comparison of the optimisation results for simulated irrigation on a turfgrass soccer playground in Stuttgart–Echterdingen in the main season 2017.

	Solver algorithm applied	Soil Water Storage Capacity	Soil Layer Thickness	Mean annual Irrigation Costs	Overall annual Costs
Original Parametrisation	–	25.0	148.8	0.53	0.655
	GRG Nonlinear	24.4	145.2	0.52	0.642
	EA (Evolutionary Algorithm)	50.1	298.2	0.29	0.541
Unit		l/m²	mm	€/m²/a	€/m²/a

By optimisation for a 10 a depreciation period, all soil layer thicknesses got increased to values between 153 and 159 mm, except the one for the Alps town Garmisch-Partenkirchen with 133 mm soil layer thickness. After optimisation, there are for all locations considerable irrigation cost savings. There are reductions of the overall annual costs for all locations, the smallest one for Garmisch-Partenkirchen, the biggest ones for Stuttgart-Echterdingen and Bernburg/Saale (Nord). In the optimised cases with a 30 a depreciation period, the soil layer thickness gets increased further for all cases, but its values tend to differ more, possibly because local weathering conditions like longer dry and wet periods or occasional heavy rainfalls are getting more important: the smallest is 198 mm in Manschnow, the biggest one 246 mm in Stuttgart Echterdingen. For the mountain town Garmisch–Partenkirchen, a soil layer thickness of 208 mm is calculated. This could be due to longer sunny and dry periods, caused by foehn winds crossing the Alps from South to North.

Table 2-9 compares the optimised soil water storage capacity and the optimised overall costs for depreciation periods of 10 a and 30 a. Except for Garmisch-Partenkirchen, the soil water storage capacity is ~ 29–59% bigger for 30 a depreciation periods. For 30 a depreciation periods, overall annual costs are getting reduced by 28-52%. Therefore, designing for the long term seems to be quite important although construction costs might be higher. The case for Garmisch-Partenkirchen is an interesting one, as already mentioned, above: For 30 a depreciation periods, the optimised soil layer storage capacity is quite comparable to the ones for Hamburg-Neuwiedenthal/Frankfurt/Main-Westend and Manschnow. This indicates that time series with typical local weathering could be more important than mean annual precipitation for vegetation layer design for a given location.

Table 2-8: Optimisation Results for simulated Irrigation on a Turfgrass Soccer Playground at various Locations in Germany from 1992 to 2017 with depreciation periods of 10 and 30 a

Name	Stuttgart-Echterdingen			Bernburg/Saale (Nord)			Hamburg-Neuwiedenthal			Unit
CDC Station ID	4931			445			1981			–
Latitude	48.6883			51.8218			53.4777			°
Longitude	9.2235			11.7109			9.8957			°
Height over Standard Elevation Zero[a]	371			84			3			m
Climate classification[b]	Temperate oceanic (Cfb)			Temperate continental (Dfb)			Coastal temperate oceanic (Dfb)			–
Mean annual Precipitation[c]	727.4			489.6			794.7			mm/a
Mean temperature[d]	9.93			9.44			9.70			°C
Optimised?	–	✓	✓	–	✓	✓	–	✓	✓	–
Depreciation Period	10	10	30	10	10	30	10	10	30	a
Soil Water Storage Capacity	20.2	25.9	41.3	20.2	26.7	40.4	20.2	26.1	36.4	l/m²
Substrate Layer Thickness	120	154	246	120	159	241	120	155	216	mm
Mean annual Irrigation Costs	0.706	0.516	0.386	0.780	0.584	0.497	0.522	0.384	0.310	€/m²/a
Overall annual Costs	1.008	0.905	0.593	1.082	0.984	0.699	0.824	0.776	0.492	€/m²/a

Name	Frankfurt/Main-Westend			Garmisch-Partenkirchen			Manschnow[e]			Unit
CDC Station ID	1424			1550			3158			–
Latitude	50.1269			47.4831			52.5468			°
Longitude	8.6694			11.0623			14.5452			°
Height over Standard Elevation Zero	124			719			12			m
Climate classification	Warmer temperate oceanic (Dfb)			Cool continental (Dfc), North side of the Alps			Temperate continental (Dfb)			–
Mean annual Precipitation	640.1			1,301.0			512.1			mm/a
Mean temperature	11.35			7.52			9.61			°C
Optimised?	–	✓	✓	–	✓	✓	–	✓	✓	–
Depreciation Period	10	10	30	10	10	30	10	10	30	a
Soil Water Storage Capacity	20.2	26.6	34.2	20.2	22.4	34.9	20.2	25.6	33.2	l/m²
Substrate Layer Thickness	120	159	203	120	133	208	120	153	198	mm
Mean annual Irrigation Costs	0.694	0.513	0.458	0.252	0.196	0.081	0.788	0.616	0.556	€/m²/a
Overall annual Costs	0.996	0.912	0.629	0.554	0.532	0.255	1.090	1.001	0.722	€/m²/a

[a] Standard Elevation Zero of the German Mean Height Reference System.

[b] According to Klöppen-Geiger. See Murray et al (2007), adapted. Michael (2015) et al., p. 54 provide a more detailed climate zone segmentation for Germany into 22 classes with comparable precipitation and months of growth. The top-left map in Ibidem, p. 55 suggests considering as well areas tempered by sea breezes and with Föhn influence (dry winds from the south over the Alps). The input data for Ibidem, p54 is for the years 1961-1990 and hence does not reflect climate change in the last 27 years.

[c] Calculated from the RSK daily precipitation time series data.

[d] During the period of the time series. Calculated on basis of the TMK daily mean temperature time series data.

[e] Mean annual precipitation and mean temperature: Missing RSK and TMK values were substituted with the mean of the present ones. This was carried out for 39 RSK and 16 TMK of 9,497 total values.

Table 2-9: Optimisation results for simulated irrigation on a turfgrass soccer playground at various locations in Germany from 1992 to 2017 with depreciation periods of 10 and 30 a

Station name (CDC station ID)	Mean annual precipitation	Mean temperature	Optimised soil water storage capacity with 10 a depreciation period	Optimised soil water storage capacity with 30 a depreciation period	Optimised overall costs with 10 a depreciation period	Optimised overall costs with 30 a depreciation period
Bernburg/Saale (Nord) (445)	489.6	9.44	26.7	40.4	0.984	0.699
Manschnow (3158)	512.1	9.61	25.6	33.2	1.001	0.722
Frankfurt/Main–Westend (1424)	640.1	11.35	26.6	34.2	0.912	0.629
Stuttgart–Echterdingen (4931)	727.4	9.93	25.9	41.3	0.905	0.593
Hamburg–Neuwiedenthal (1981)	794.7	9.7	26.1	36.4	0.776	0.492
Garmisch–Partenkirchen (1550)	1301.0	7.52	22.4	34.9	0.532	0.255
	l/m²/a	°C	l/m²	l/m²	€/m²/a	€/m²/a

2.4.3 Sensitivity analysis: Depreciation period and substrate layer thickness

Figure 2-7 shows the influence of the depreciation period length on the mean annual irrigation costs and the overall annual costs with standard[21] and optimised substrate layer thick- nesses for Stuttgart-Echterdingen for a simulated time span from 1992 to 2017.

The mean annual irrigation costs with a soil layer thickness of 80 mm do amount 295% of the corresponding ones for an optimised layer thickness with a depreciation period of 10 a. With a depreciation period of 30 a, this percentage rises to 392% and to 444% for a depreciation period of 40 a. Irrigation costs for a substrate layer thickness of 120 mm are quite more favourable than for a layer thickness with 80 mm, but are still 137-207% of the ones for an optimised substrate layer thickness.

For the cases with optimised soil layer thicknesses, it can be seen that the mean annual irrigation costs are dropping with longer depreciation periods: there are cost savings of 33.7% between the case with a depreciation period of 10 years and the cases with depreciation periods of 35 and 40 a. The overall annual costs drop by 41.1%, when comparing the 10 a depreciation period case to the one with 40 a. The overall annual costs of 1.57 €/m²/a with an 80 mm substrate layer thickness for a depreciation period of 40 a do form 294% of the ones with an optimised substrate layer thickness.

[21] The standard soil layer height of 80 mm corresponds to a soil water storage capacity of 13.4 l/m²; the standard soil layer height of 120 mm corresponds to a soil water storage capacity of 20.2 l/m².

Hence, an optimised substrate layer thickness is both recommendable for keeping costs down for short and long depreciation periods, here.

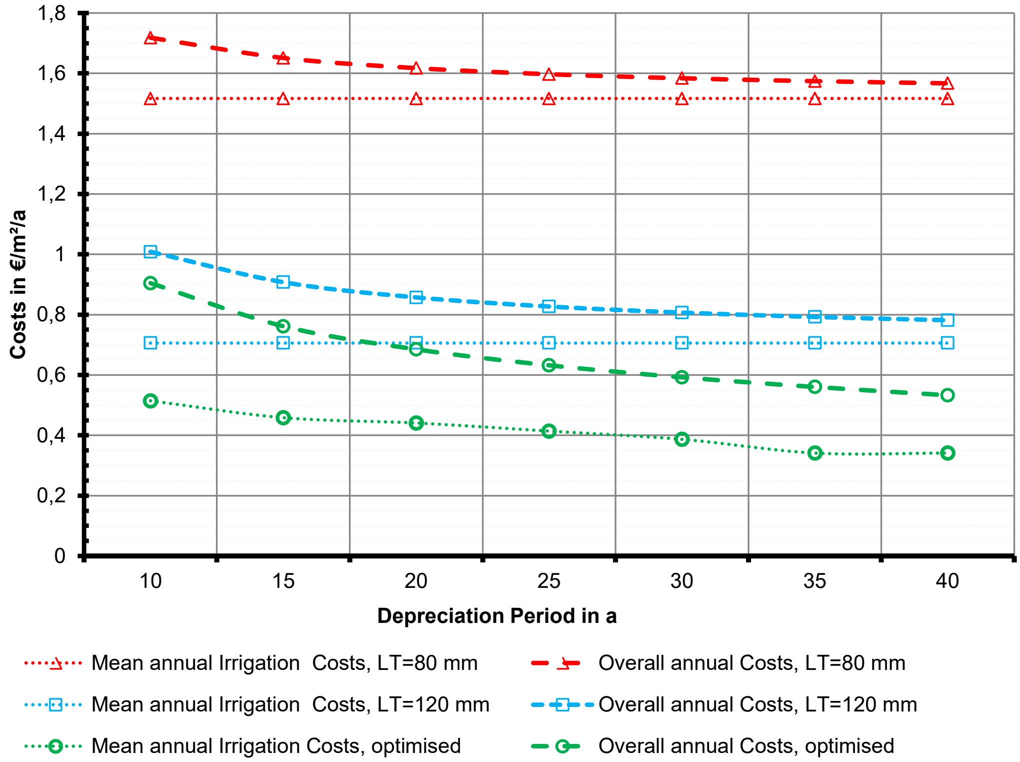

Figure 2-7: Sensitivity Analysis for Overall Annual Costs as a Function of the Depreciation Period for a Turfgrass Soccer Playground with standard and optimised soil layer height in Stuttgart-Echterdingen, from 1992 to 2017.

2.5 Discussion

After categorising the presented approach in decision support research, the modelling approach is being discussed. The following section showcases relevant aspects for key stakeholders.

2.5.1 Categorisation of this approach in decision support system research

Power (2001) suggests defining decision support systems "*as a broad category of information systems for informing and supporting decision makers*" with the intention "*to improve and speed up the processes by which people make and communicate decisions*".[22] They feature "*mathematical-analytical models as major component*" and rely on "*choosing the appropriate model as key design issue*".[23] The presented approach does neither feature a software implementation nor an information system, but a supporing method—to be implemented and provided in an executable form for decision makers intending to improve decision quality and certainty by "making sense

[22] Power (2001, p. 432).
[23] Ibidem, p. 436.

of structured data".[24]According to the criteria of Power (2001), the method can be seen as a model-driven one, using "*data and parameters provided by decision makers to aid them in analysing a situation*"[25] that is function-specific, as it helps accomplishing a specific task.

2.5.2 Modelling approach

The used model relies on measured precipitation and estimated potential evapotranspiration time series. The stock-flow model for the soil water balance is kept quite simple and does not include functional dependencies between soil layer thickness and capillary water storage capacity. Hence, for analyses for a given location of a soccer field, it is necessary to rely on water balances for a specified substrate with a chosen turfgrass type under well-approved soccer sportsground maintenance, e.g. captured by a lysimeter. The core behaviour of this water balance model could be approximated by non-linear regression models, covering functional dependencies for e.g. capillary water uptake, usable soil water storage capacity in function of substrate layer height and evapotranspiration.

Field capacity is a well-defined measure[26] for the upper limit of available water to plants. Its characterisation for the approach in this contribution needs to be carried out at with substrate at installation density and well-grown turfgrass on it. The other relevant parameter for calculating the usable soil water storage capacity is here not the permanent, but the starting point for wilting of turfgrass, as drought stress should be avoided. Hence, this parameter is an observation-based one and therefore, the usable soil water storage capacity, as well.

The irrigation instructions in this work are for DFB soccer sportsgrounds with layer thicknesses of 80-20 mm and hence for usable water storage capacities of approximately 13-20 l/m². For depreciation periods of 30 years, the optimisation algorithm suggests much higher water storage capacities, between 33.3 and 41.4 l/m^2 for the locations in Table 2-8. Therefore, the following constants could be varied as well by the optimisation algorithm: the irrigation quantity for 1 day and the precipitation forecast horizon.

2.5.3 Relevant aspects for key stakeholder groups

The following aspects are relevant for key stakeholders in Germany. They should be mostly transferable to other countries with similar semi-humid and humid temperate climate.

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[24] Ibidem, p. 435.
[25] Ibidem, p. 433.
[26] See e.g. Zotarelli et al. (2010) or Cong et al. (2014).

2.5.3.1 Substrate providers for turfgrass sportsgrounds

Using substrates with a superior usable soil water storage capacity could be an alternative to avoid higher substrate layers. Such substrates might be composed e.g. with shares of porous aggregates like lava. In order to keep the transport cost share low, on-site mixing could be considered, as porous aggregates can be comparatively lightweight.

2.5.3.2 Turfgrass sportsground planning and construction companies

The presented method permits finding a cost optimum for substrate costs and irrigation costs in a given depreciation period under local weathering conditions. The presented approach needs to be adapted to local construction and substrate costs.

2.5.3.3 Sports clubs and municipal bodies as sportsground owners

The results of this contribution show that irrigation costs do clearly go in function of sportsground design. Hence, call for tenders for turfgrass sportsgrounds should explicitly ask for resulting irrigation costs, taking local weathering conditions into account. This might lead to increased construction costs, but to considerable savings on the long term. Modern turfgrass sportsground substrates and design do come as well with quite good water discharge for heavy rain and cloudbursts and do hence permit extended usage times and therefore lower costs per usage hour.

2.6 Conclusions

Although the presented work still comes with a number of uncertainty factors, it shows that the simulation-based technical design of turfgrass soccer playgrounds comes with a significant improvement potential with respect to finding an economical optimum between construction and irrigation costs. The presented methodology relies on publicly available data and was implemented in Microsoft® Excel. Hence, it could be easily adopted by sportsground planners. Due to increased requirements in sports field construction, an improved adaptation of the structural properties of turfgrass soccer playgrounds is necessary. The balance between infiltration rate and water storage capacity of the turf base layer is of great importance. Therefore, precise planning of the thickness of the lawn base layer is necessary. In the context of this publication, a model written in Excel was developed to optimize the costs and benefits of a lawn base layer. The long-term weather records of the DWD are included in the calculation. The potential evapotranspiration of the AMBAV was used to calculate the model. The user only has to enter certain input variables, such as the maximum amount of irrigation, and then receives the optimum water holding capacity of the lawn base layer. From this, the thick- ness and design of the vegetation layer can be determined. The model was tested at five locations and resulted, for example, in a required water storage capacity of 50.1 l/m^2 for the city of Stuttgart. By comparing the evaolutionary algorithm with the GRG nonlinear algorithm, a significantly improved adaptation could be determined. In order to increase the applicability in practice, Excel was used, as this software is used by most sports field designers and planners. Further research will verify the models on existing sports fields, for example by lysimeters.

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3 Development and evaluation of a device to incorporate biodegradable textiles into sports turfs[2]

Bastian Stürmer-Stephan, Jörg Morhard, Hans W. Griepentrog

In Germany, approximately 55,000 sport pitches are in use regularly. Sport pitches should have a period of use of about 800 h/year regardless of weather conditions. The sandy root zones of the pitches generally need artificial irrigation. This results in excessive water use during drought. The incorporation of a biodegradable textile, further named nonwoven is intended to improve the water availability for the turf cover and elongate the period of usage of standard sport pitches. The present study aims to develop and evaluate a device for the vertical incorporation of a nonwoven 150 mm in height into existing pitches at a maximum depth of 170 mm. The device cuts the turfgrass, opens a slit with a box coulter and incorporates a nonwoven into the root zone layer. An attached pressure roller then recompacts the disturbed surface area. A field trial was conducted to evaluate the device's variation in working depth and recompaction efficiency, as well as to assess the damage to the turf cover. The variation of the working depth was less than 20 mm. The soil recompaction, measured as penetration resistance, was similar to the status quo, except in the area close to the nonwoven, where the recompaction failed. The turf damage was less than 15 % of the ground cover, which meets the playability requirements. While the device worked within its specifications, further research needs to be conducted in order to investigate the benefits of nonwovens with regards to water use, the impact on the turf cover and its wear.

Keywords

lawn; water; device; nonwoven; turf; sport; pitch

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3.1 Introduction

Soccer, one of the most common sports worldwide, is performed on turf surfaces specially designed for this purpose. Since these surfaces are in use during all seasons, they must remain playable during most weather conditions. Turfgrass for this purpose normally grows on an artificial layer-by-layer system. Evapotranspiration from the vegetation layer as well as local weather conditions should be considered with regards to the vegetation layers' water storage capacity (Maschler et al. 2019). The presented research, embedded in the project RasenTex (ZIM-Kooperationsprojekt ZF4060029AW7, Bundesministerium für Wirtschaft und Energie), aims to improve a vegetation layer system while following the recommendations of the DIN 18035-4:2012-02 standard. This system is intended to be explicitly composed of locally available soil components (Maschler et al. 2019). For improving sportpitches, a nonwoven is actually in research. The nonwoven is expected to enable water from the drainage layer to rise into the root zone of a sport pitch. The present study aims to develop and evaluate a device for the vertical incorporation of a biodegradable nonwoven into the existing vegetation layer of sport pitches. In Germany 55072 soccer pitches were in use in the year 2000 (Senatsverwaltung für Bildung, Jugend und Sport et al. 2002). Wherein 33139 are classified as large sport pitches, with a size of at least 7,000 m² (DFB 2011). High water permeability is necessary in order to discharge heavy rain. On the other hand, a sufficient water supply of the turfgrasses is a major challenge for planning and constructing sports pitches (Huang and Fry 2008; DIN 18035-4 2018). As a consequence, irrigation is necessary. Unfortunately, intensive and frequent irrigation leads to high water consumption. The average irrigation demand of a sports pitch in Germany lies between 75 and 250 mm per year, depending on the region (DFB 2011). Daily water consumption of sport pitches ranges from 2.5 mm and 7.5 mm (Leinauer et al. 2012). Due to climate change, and especially in regions with low precipitation, an intensive irrigation is necessary. The irrigation season in Germany starts in May and ends in September. High temperatures above 15 degrees allow water demand to rise up to 8 l/day in summer (DIN 2003; DFB 2017). During the winter, usually no irrigation is necessary, however the higher precipitation needs to discharge. Due to more frequent drought periods as a result of climate change, irrigation may be prohibited or restricted (Huang 2008). Because of this, future sport pitches need improved water permeability and simultaneously enhance water supply to the turfs. Turf pitches are standardized within DIN 18035-4 (Lund et al. 2018). The standard recommends a layer-by-layer structure of the pitch. Starting from the upper layer, the proposed structure consists of the rootzone, the drainage and the subgrade. The subgrade consists of the existing subsoil. If the subgrade shows a high water infiltration rate only a rootzone layer with a recommended height of 100 mm is used (Lund et al. 2018). The water infiltration rate of the subgrade must be at least 30 mm/h. In case of an impermeable subgrade, the standard recommends the use of an additional drainage layer. For this purpose, the drainage layer must have a minimum height of

120mm and a water infiltration rate of more than 180 mm/h. In addition, the unevenness of the drainage layer has to be less than 20 mm on 4 m length. The main layer of standard sport pitches is the so-called rootzone layer. With regard to hydrology, the rootzone layer must have a water infiltration rate of at least 60 mm/h. At the same time, the layer must have a water holding capacity of 30 Vol.-%. The unevenness of the layer must be less than 20 mm on 4 m length. The DIN 18035-4 standard allows construction methods to be adapted if the general requirements of the standard are met (Lund et al. 2018). Regarding these requirements, the height of an existing sport pitch is about 220 mm. Therefore, a nonwoven need to be to incorporated between the drainage layer and the main rooting zone of the sport pitch. It should be placed at a depth of 170 mm to the level of the ground with a high accuracy. The assumption of a depth of 170mm was made due to the 220mm height of a standard sport pitch. The nonwoven works like a surface irrigation system (Abidin et al. 2014). The nonwoven should transport the water from the drainage layer to the root zone due to capillary forces.

To optimize the water balance in existing sport pitches or golf courses, different techniques are used. If the water permeability is low, a slit or a bypass drainage increase infiltration rates without the need for reconstruction (Adams 1986; Cereti et al. 2004; BAIRD 2005). The operation principle of these machines is very similar to the machine developed in this study. For slitting and incorporating sand or drainage pipes they are constructed with rotating or oscillating blades, that open a trench and then refill the trench with the material, which is to be incorporated (John A. Bentley 2003; Laurence McGann 1992; Rogmann). Because of their weight, these machines apply a high surface pressure and often damage the turfgrass (James et al. 2007a). This circumstance may require more maintenance efforts and prolonged usage breaks for turfgrass recovery. The minimization of usage breaks, however, is a central goal of the overall management of sport pitches.

The objective of the study is to construct and evaluate a device for the vertical incorporation of a nonwoven into the vegetation layer of existing sports pitches with the subsequently specified requirements.

The incorporating device has to fulfill three tasks. It has to vertically precut the turfgrass, then open a slit vertically, insert the nonwoven, close the slit, and finally to recompact the root zone. The nonwoven has to be installed rectangular to the surface to prevent the nonwoven from being exposed on the top surface.

The working objectives of the present study are the following:

- The accuracy of the working depth must not exceed ± 20 mm.
- Passively driven technology.
- The tractive force requirement of the device should be kept low, in order to be able to be attached to low powered towing vehicles.

- The weight of the device has to be minimized, in order to ensure that the three-point linkage can carry it.
- The ground cover of the turf may not be reduced by the incorporation.
- The overall length of the device has to be short in order to keep the turning area as small as possible.
- The surface has to be recompacted in order to restore evenness and connect the nonwoven to the pores of the rootzone and the drainage layer.
- Reduction of turf damage.

3.2 Materials and methods

3.2.1 Test area and trial layout

The tests described were conducted between August 23th, 2019 and September 8th, 2019 on turf plots, built according to the DIN 18035-4 standard (DIN 18035-4 2018). The test site was located at the experimental station Heidfeldhof in 70599 Stuttgart, Germany. Three replications (Fig.2), each with a length of 11 m and a width of 4 m, were excavated and a layer-by-layer structure was installed. Each plot consisted of a rootzone layer with a thickness of 130 mm and an underlying drainage layer with a thickness of 120 mm. The sandy soil mixtures of both layers were produced and installed in October, 2018 according to the DIN 18035-4 standard. The root zone mixture had a particle size distribution of 13 % by weight < 0.063 mm, 77 % by weight between 0.063 mm and 2 mm and 10 % by weight between 2 and 6 mm. A standard turf seed mixture type 3.1 (FLL 2019) with a seed rate of 40 g/m² was seeded in October 2018. The standard turf seed mixture consists of 50 % perennial ryegrass (*Lolium perenne* L.) and 50 % Kentucky bluegrass (*Poa pratensis* L.) seed. The mowing height of the established turfgrass was 30 mm, using a rotary mower. At the time of installation the unevenness of the rootzone layer was less than 20 mm on 4 m length, measured according to DIN 18035-4 The standard construction design was improved by vertically incorporating a biodegradable nonwoven into the layer structure. This altered construction then consisted of four components: turfgrass, root zone layer, biodegradable nonwoven, and drainage layer. To test the device described in section Material and Methods biodegradable viscose nonwoven bands with a height of 150 mm and a width of 4-5 mm were incorporated on August 26th, 2019. The distance between the parallel tracks was between 200 and 300 mm to avoid severe injury to the turfgrass. Furthermore, each track had a length of 10 m to avoid boundary effects. Eight tracks were applied at each plot (Figure 3-1). The untreated area of the 4 m wide plots should be used as control, but due to the low water content of 10.2 Vol. %. no penetrometer measurements could be done (Figure 3-2). The installation was carried out at speeds between 1 and 2 km/h, using a John Deere 4049 (John Deere, Illinois, USA) with municipal tires.

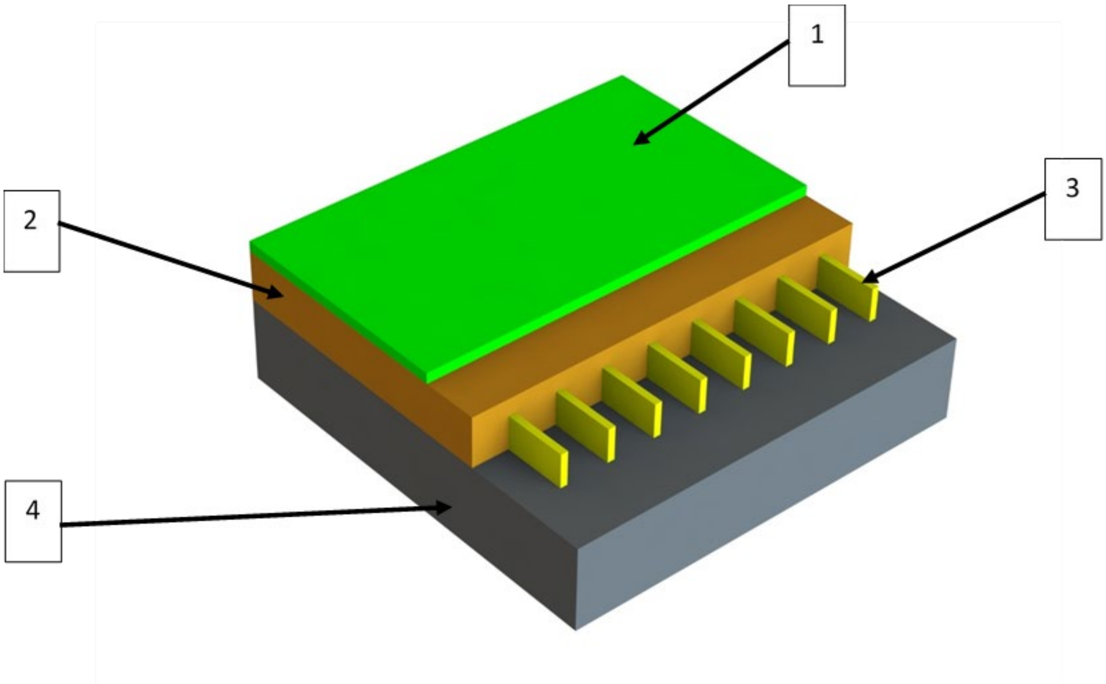

Figure 3-1: Vegetation layers for sports turfs with incorporated nonwoven: 1) turfgrass, 2) rootzone layer, 3) vertical incorporated nonwoven, 4) drainage layer. (© B. Stürmer-Stephan)

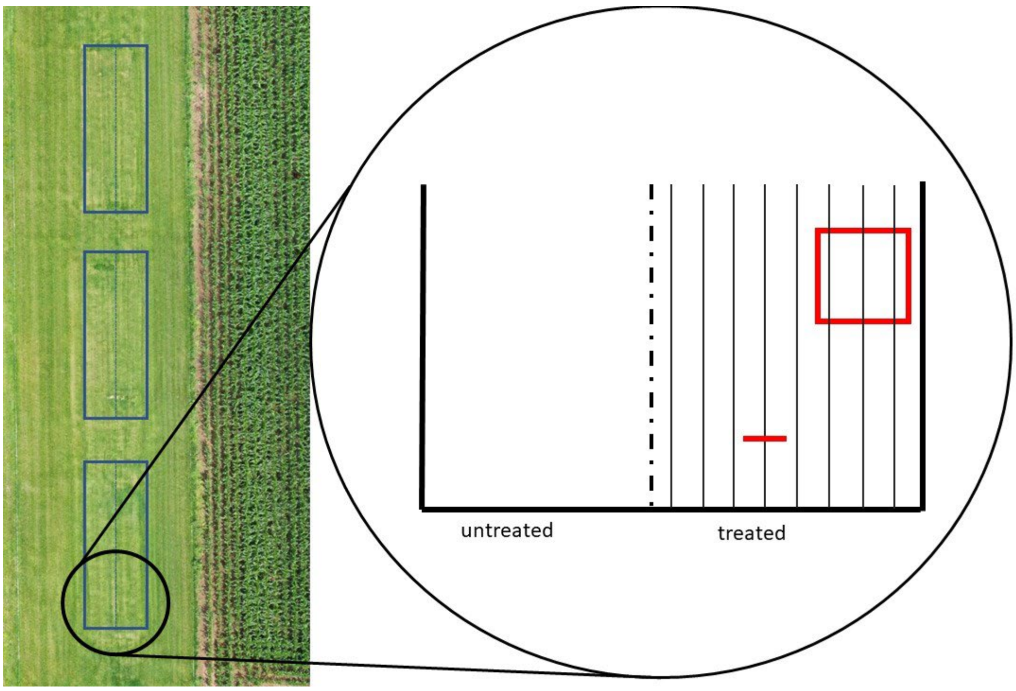

Figure 3-2: The three measured replications (plots). The detailed view shows the position of the incorporated nonwovens, the position of one random sample with the wooden frame (red square) and one position of the six measurements points with the penetrologger (red line). Ten samples were performed for the visual scoring and four samples were done with the penetrologger in each plot.

3.2.2 Characterization of the nonwovens

The dimensions of the nonwoven bands are important. The nonwoven bands should have a width between 4-5 mm and a height of 150 mm. The width should not be less than 4 mm, in order to preserve sufficient tensile strength, and not exceed 6 mm, which would disrupt the vegetation layer. Since the nonwoven needs to connect the drainage layer with the rootzone layer, a height of 150 mm was chosen. The nonwoven for the experiments had a density of 0.175 g/cm³ (GEBR. RÖDERS AG, Soltau, Germany). Considering the length of an average sport pitch, a strip of nonwoven of about 105 m is to be incorporated during one crossing. Its weight is about 12 kg. Due to the production method, 50 m of nonwoven carrying a weight of 6 kg are stored on one drum. The tensile strength of the nonwoven, which base material is viscose, exceeds 450 N. The capillary structure of the nonwoven may be optimized for transporting water from the drainage layer into the root zone of the turfgrass. Due to the biodegradable properties of the material, disposal costs can be reduced (MASCHLER et al. 2019). Figure 3-3 shows an incorporated nonwoven, exposed on one side, connecting the drainage layer with the rootzone layer.

Figure 3-3: Incorporated nonwoven connecting rootzone layer and drainage layer in one of the test plots. (© B. Stürmer-Stephan)

3.2.3 Technical description of the device

The device developed as part of the present study consists of six major components (Figure 3-4). The entire device is pulled and guided by the rear three-point linkage of a towing vehicle. The design of the three-point linkage corresponds to category 1 as described by the ISO 730:2009 standard (ISO 730:2009). Central component of the device is the frame (A). It has an overall length of 1.8 m and a width of 0.8 m. It is manufactured from square steel tube with the dimension of 100 mm height by 100 mm width. The frame mainly consists of three cross bars linked by side members. The forces occurring at the three-point attachment are dissipated via stiffening struts in the last cross bar. This cross bar carries the roller for the slit recompaction.

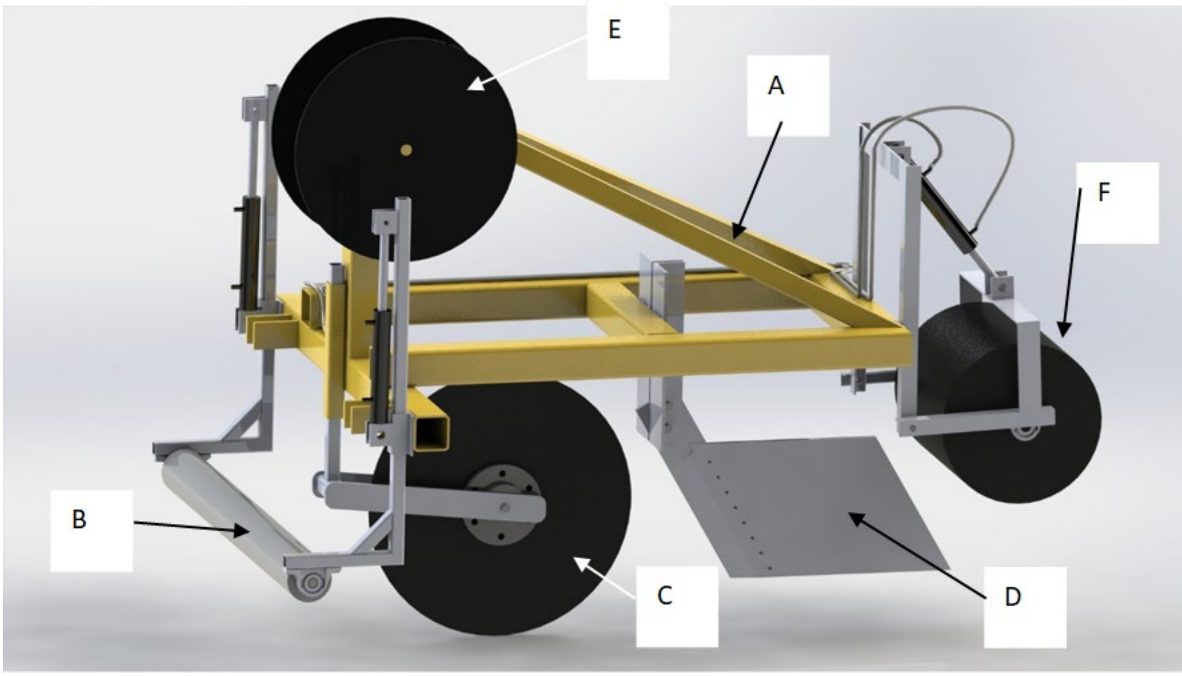

Figure 3-4: Technical overview of the developed device A) machine frame, B) roller for depth control, C) cutting disk to precut vegetation layer and rootzone, D) box coulter to open the soil and guide textile ribbon rectangular into the created slit, E) reservoir drum for nonwoven textile and F) roller for slit recompaction. (© B. Stürmer-Stephan)

The roller for depth control (B) and the cutting disc (C) are attached to the first cross bar in driving direction. The main purpose of the cutting disc is to cut the turfgrass and simultaneously to pre-form a slit in the vegetation-layer. The cutting disc has a diameter of 58 cm and a width of 5 mm. To overcome the problem of clogging, the use of a passively rotating disc is advantageous. Due to the principle of a pulling cut and the sharp cutting edge, the cutting disc cuts easily through the roots (Nieuwenburg et al. 1992). The working depth of the cutting disc can be adjusted in five height settings by means of a hole grid. The hole grid has uniform spacing of 50 mm to change the working depth in relation to the box coulter. Adjusting the working depth of the cutting disc allows a flexible adaptation to the operating conditions and to the shear strength of the vegetation-layer. The cutting disc is driven by the forward movement of the pulling vehicle, there is no active drive in order to keep the weight of the device low. If the sport pitch is dry and has a high penetration resistance the device can be ballasted with weights.

The box coulter (D) is displayed in Figure 3-4. It opens the slit, guides and inserts the nonwoven. For that purpose, the box coulter has a width of 15 mm and a cutting angle of 60 degrees. It consists of two metal furrow shaping plates on each side. They have a length of 40 cm and a height of 25 cm. Their function is to keep the slit open and to guide the nonwoven inside the box coulter. The guide plates are mounted with screws to allow simple maintenance or replacement. To avoid a penetration of the substrate from the bottom, the box coulter is closed at the bottom. This arrangement leads to a displacement of soil material in the direction of the sole and the walls of the slit. In the box coulter, a ball bearing is used to guide the nonwoven in height. The nonwoven unrolls by itself from the nonwoven coil (E) with a maximum diameter of 70 cm, depending on the coil dimensions. During the unwinding, the nonwoven is elongated. Due to its specified tensile strength, no active drive of the reservoir drum is necessary. The guidance is facilitated due to the fact that no draping of the nonwoven is expected. This was assumed due to the high tensile strength of 450 N and the 5 mm width of the nonwoven. In all tests no draping was observed. Different sport pitches based on different construction models may require varying working depths of the device. The condition is that the device can be guided precisely along the ground surface. Therefore, a height guidance is implemented via a continuously height-adjustable guide roller. The working depth is adjusted by a 1.2 m wide guide roller with an outer diameter of 70 mm (B). The working depth can be continuously adjusted via two hydraulic cylinders with a stroke of 20 cm. Since each side of the guide roller is equipped with a hydraulic cylinder a flow divider ensures a synchronized movement of both hydraulic cylinders. Check valves prevent the hydraulic cylinder from pressure loss. The hydraulic cylinders are controlled by the double-acting control units of the towing vehicle. A scale can be used to check the current working depth and for the placement depth of the nonwoven. For recompaction of the rootzone layer, a pressure roller with a width of 45 cm and a diameter of 30 cm is used (F). The pressure roller recompacts the layer surface and closes the slit after the incorporation of the nonwoven (Figure 3-5). The compacting pressure of the pressure roller can be adjusted by filling the pressure roller with water. Additionally, the compacting pressure can be increased by a hydraulic cylinder, which transfers load from the device to the pressure roller by extending the piston. The hydraulic cylinder is adjusted by the control valves of the towing vehicle. A built-in scale further facilitates the adjustment of the recompaction pressure. A built-in check valve prevents the hydraulic cylinder from pressure loss.

Figure 3-5: The developed device incorporates a 150 mm height nonwoven in a depth of 170 mm on one of the test plots. The box above the coulter can be used for testing the incorporation of additional sand, but this feature is not investigated within this work. (© B. Stürmer-Stephan)

3.2.4 Determination of the machine working depth

For evaluating the correct working depth of the machine, the level of the ground of the plot and the position of the box coulter had to be determined. First the ground of the plots was determined with a highly accurate robotic landscape surveying instrument (Trimble SPS930) and a monopod with a retroreflecting triple prism (Trimble M900) (Trimble, Sunnyvale, USA). Turf surface points were measured in grids of 0.7 x 0.7 m. A surface was fitted by the 2.5 D quadratic routine, included in the software Cloud-Compare V 2.11 alpha (GPL software). The surface was used for calculating the mesh-cloud distance to the depth of the box coulter. The coulter of the present study, fixed to the rigid frame forms a single unit. So the installation depth of the nonwoven could be measured at the highest point of the machine using the prism. This indicates that the tracked position is 0.6 m above the bottom of the box coulter. The desired installation depth of the nonwoven was 20 mm beneath the surface, measured from the upper edge of the nonwoven. Thus, the desired working depth of the box coulter was 170mm. This measurement method determines the working depth of the machine. This method thus does not directly determine the depth of the fleece, but at 2-3 samples per plot it was visually checked whether the fleece was installed correctly. Since no twists were detected in the fleece, the working depth of the machine was set equal to the deposit depth of the fleece.

In post processing, the entities of the measured coordinates of the machine were reduced to the size of the plots by using Cloud-Compare. Afterwards the mesh-cloud distance between the position of the box coulter and the fitted surface was calculated and the distance travelled by the device was plotted for the central 10 m of each plot. The root mean square for the regression for all eight profiles of each plot was calculated. The average for each plot is presented in the results. The root mean square was used because the plots had a slope and otherwise the mean of the measurements would not be accurate. Furthermore, the data of all eight profiles were interpolated with SigmaPlot 14.03.192 (Systat Software GmbH, Erkrath, Germany) to the same lateral distance of 50 mm between data points. Afterwards the mean differences to 170 mm (nonwoven with 150 mm height and 20 mm installation depth) for each data point of the eight interpolated profiles were calculated. Additionally, the standard deviation of this interpolated profiles were calculated for each of the data points.

3.2.5 Determination of the recompaction and incorporation

For assessing the recompaction, the penetration resistance was measured transverse to the installation direction of the nonwoven, that is working direction of the device. This means the penetration resistance was measured along a cross-section of the slit surrounding soil. Measurements were done using an electronic penetrometer of the type Penetrologger (Ejkelkamp Soil & Water, Giesbeeck, Netherlands). The penetrometer measurements were taken up to a depth of 200 mm. Three measurements were carried out on both sides of the nonwoven in intervals of 20 mm. They were taken transverse to the installation direction, starting at each side of the nonwoven. Four repeated measures were performed for each plot, each in a different position within the plot (Figure 3-2). The positions were located in zones where visually no side-effects could be observed. For each plot a contour map was created, based on the arithmetic means of the four repeated measures. The contour map routine of Sigma Plot was used. For the assessment of the results, the soil moisture was measured with a time domain reflectometry testing probe (IMKO Micromodultechnik, Ettlingen, Germany). The average soil moisture content in the presented study was 10.2 Vol. %. Due to the low water content of the rootzone layer, no control measurements could be taken at the remaining part of the plots because the value of penetration resistance was out of the measuring range of the penetrometer. This means the penetrometer could not penetrate the sandy root zone layer at the remaining part of the plots, where no nonwoven was incorporated.

3.2.6 Determination of the turf damage

Minimizing the damage of the turf was important when developing the device of the present study. Visual scoring of the ground cover in percent was used for evaluating the impact of the machinery on the turf, using a wooden frame according to DIN 12231 (DIN EN 12231 2003) of one square meter size (Figure 6). Defines a square pattern accordingly 100 x100 mm. The visual scoring was performed in increments of 10 %, from 0 to 100 % ground cover. Visual scoring took place three days before incorporation of the nonwoven, shortly after incorporation of the nonwoven, and eight weeks afterwards. Results of visual scoring before incorporation were used as untreated for the trials. Ten replicate measures were taken for each plot (Figure 3-2). Descriptive statistic was done using Rstudio Version 1.1.463, Cloud Compare V 2.11 alpha and SigmaPlot 14.03.192. Arithmetic mean and standard deviation were calculated.

Figure 3-6: Wooden frame according to DIN 12231 (2003) on a part of the treated turf. The closed slits can be recognized. (© B. Stürmer-Stephan)

3.3 Results and discussion

3.3.1 Machine working depth

In order to evaluate the variation of the working depth, the root mean square (RMS) of the eight measured profiles were calculated. Table 1 shows that the average RMS values for the plots were between 6.0 mm and 8.3 mm. The highest RMS was detected in plot 3, which may have been due to an uneven surface before the incorporation process (Table 3-1). The standard deviation ranging between 1.1 mm and 2.0 mm, was considered to be acceptable because the resolution of the landscape surveying instrument is +- 1mm. All tested plots had a RMS lower than 10 mm (Table 3-1), which met the desired accuracy. These results demonstrate that the device operates within the desired parameters.

Table 3-1: Average root mean square of the working depth in mm for each of the tested plot and the standard deviation of the root mean square (RMS) of the plots in mm.

Plot	Average root mean square (RMS) in mm	Standard deviation of RMS in mm
Plot 1	6.0	1.1
Plot 2	7.3	2.0
Plot 3	8.3	1.6

The red line in Figure 6 shows the mean difference to the desired working depth of 170 mm for each plot. For the eight profiles of the plot the standard deviation of this difference was calculated and presented as error bars in the same figure. The beginning and the end of the plots is just showed to determine the pull-in and pull-out behavior of the device (Figure 6). The results indicate that the standard deviation of the working depth of the tracks of plot 1 (a) only differ less than 1 mm. This conclusion is supported by the low standard deviations between the repeated measures of this plot. Mainly, there is a higher standard deviation at the first 2.5 m and at the last 2 m of the plot, due to boundary effects. A higher mean error above 20 mm occurs in the plot 2 (b) at the end of the plot, between 8 m and 10 m distance from the starting point (Figure 3-7). The mean errors of the intended working depth in each plot are lower than 20 mm, but by a positive tendency (Figure 3-7). These results indicate that the accuracy of the incorporation of the nonwoven is high enough, according to the conditions of the plot. According to the standard deviation a range of values lower than 7 mm is presented (Figure 3-7). The measured working depth differ significantly from the expected working depth of 170 mm during the first and the last 2 m of the plot. This may occur because the device needs more driving way and speed to penetrate the root zone during the first meters. At the end of the plot the device was pushed to the

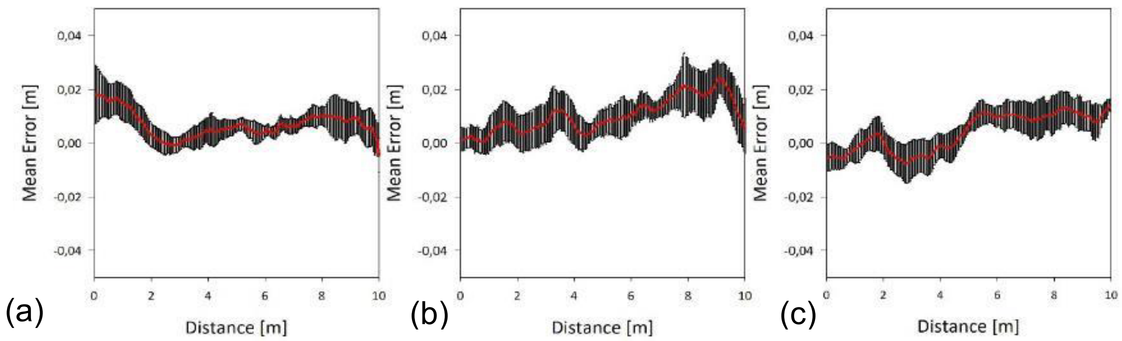

Figure 3-7: Mean errors to 170 mm working depth of the eight measured tracks on plot 1 (a), plot 2 (b) and plot 3 (c), error bars show standard deviation.

top, perhaps because the towing vehicle slowed down at the end of the plot. These observations may explain the low accuracy of the working depth at the end and the beginning of the plot and the higher accuracy in the middle part of the plot. However, no nonwoven was visually observed above the surface of the plots. A soccer shoe has cleats with a length of about 10-15 mm, so that the nonwovens could not affect players (Park et al. 2005). It is essential that the nonwoven is located more than 20 mm deep in the drainage layer in order to meet the demands of the developed turf system. The results presenting the working depth, indicate that the developed machine is able to meet these requirements. However, the measurements showed that in some areas of the plot the working depth shifts towards the surface of the pitch. For the further development of the device this result should be particularly considered. A solution could be a heavier device or a ballasting of the device. In future studies the plots should be longer, to guarantee a constant speed along the trial. A higher rotational speed of the cutting disc would result in a better working quality (Tice and Hendrick 1992). However, it must be noted that the forces acting upwards become greater (Tice and Hendrick 1992).

3.3.2 Incorporation and recompaction

In order to evaluate the recompaction of the rootzone layer by the pressure roller, the penetration resistance was measured. Figure 3-8 shows the distribution of the penetration resistance over the penetration depth, with the position of the nonwoven being depicted in the center. In the upper part of the rootzone, the penetration resistance increases by depth. It is evident that the low values up to a depth of 20 mm result from the high content of organic matter consisting of roots and thatch. The values of penetration resistance next to the nonwoven are lower than the values at a larger distance to the incorporated nonwoven. Down to a penetration depth of 40 mm, the penetration resistance is below 0.5 MPa. At the lower edge of the nonwoven, at a depth of 160 and 180 mm, the penetration resistance is lower than 1.5 MPa. Figure 3-8 shows that the lateral distribution of the penetration resistance is uniform. Only the coulter sole shows lower values compared to the values at a distance of 60 mm to the nonwoven. The reason could be the sandy root zone mix, which is lateral displaced by the box coulter, in conjunction with the very dry soil conditions. After the incorporation of the nonwoven the root zone mix may have been fallen in the newly- formed hollow space. Normally, the penetration resistance of a turf pitch which was built in accordance to the standards, is about 1 - 4 MPa depending on the soil water content and the construction method (Morhard 2004; Holzinger 2011). Results indicate, that the pressure roller leads to similar values, except of the direct surrounding of the nonwoven. In this area the recompaction failed, most probably because of the low water content of 10.2 Vol.-%. A technical solution to this issue could be an increase of the vertical load on the pressure roller or the use of another type of pressure roller, like a v-shaped pressure roller (Hinrichsen and Kushwaha 1989). On the other hand, the loosened substrate around the nonwoven increases the soil gas exchange, which is presumed to result in a better rooting of the vegetation (Bunnell et al. 2002). Therefore, in further studies the functionality of the nonwoven has to be investigated with regard to these aspects, with focus on the influence of the low recompaction on the playability of the sport surface.

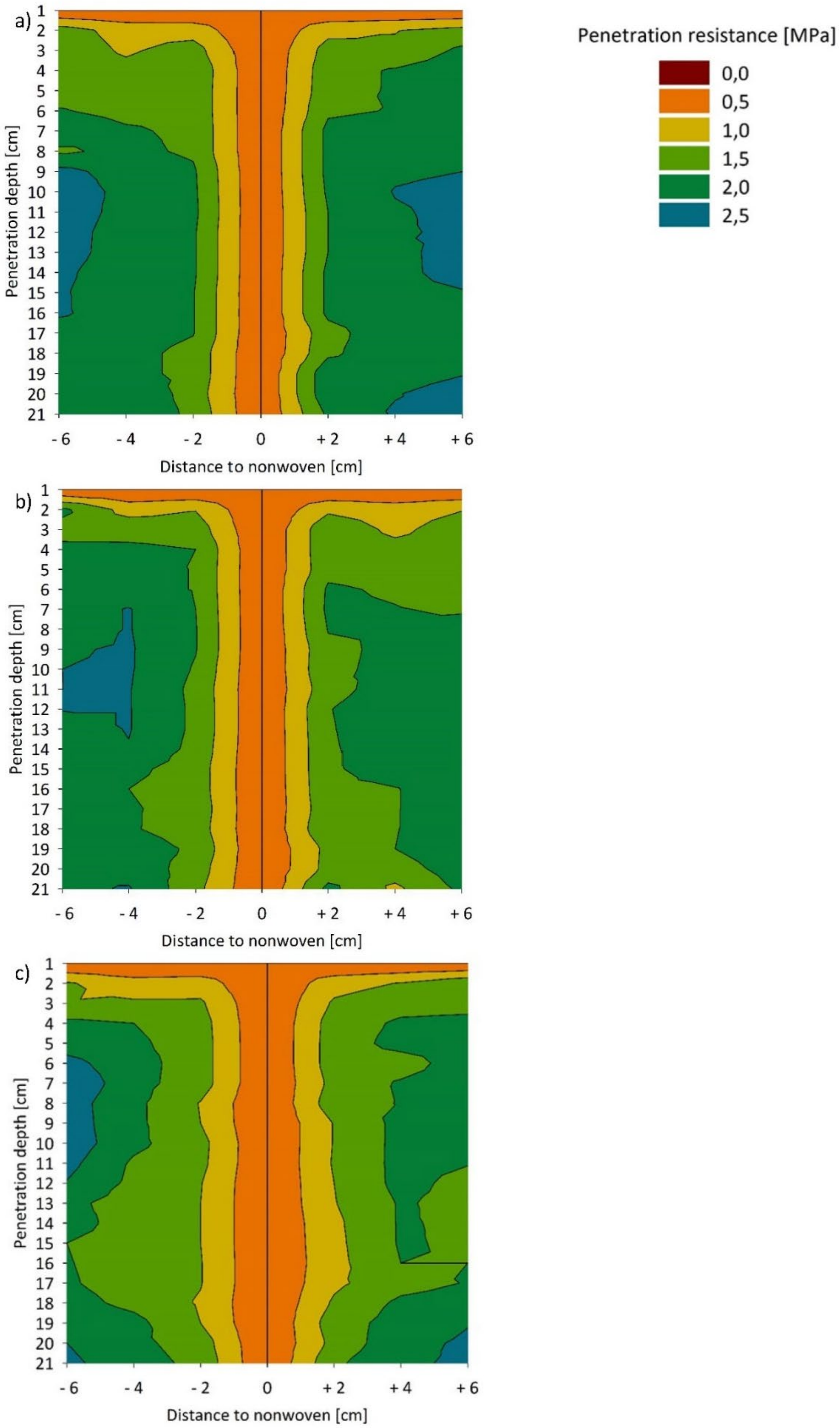

Figure 3-8: Penetration resistance (MPa) cross-section of plot 1 (a), plot 2 (b) and plot 3 (c), close to the nonwoven, after incorporation. The nonwoven position is schematically shown in the center of each figure by a grey rectangle.

3.3.3 Evaluation of the turf damage

The visual scoring of the turf damage depicted a lower ground cover after the incorporation of the nonwoven. The damage that results from the cutting disc and the pressure roller is evident but marginal. The slots of the box coulter reduce the ground cover by 10 to 15 % (Figure 3-9). However, the slots are closed and compared to James et al. (James et al. 2007c) no grass die-back was observed. Eight weeks after the treatment the ground cover did not differ from the determined status quo. The DIN 18035-4 standard requires more than 95 % coverage for acceptance of a new built sport pitch (DIN 18035-4: Sportplätze - Teil 4: Rasenflächen 2018). On the other hand, the German Football League requires a ground cover of more than 60 % for a game at national league level (DFL 2018). Regarding the ground cover, the results ensured a possible playability of the sports field even immediately after the treatment according to the German Football League (Figure 3-9). Because the original ground cover could be restored after eight weeks the device meets the desired requirements. The trials also showed, that the box coulter and the cutting disc must be perfectly aligned to avoid turf damage.

To compare the results with the current state of research, the device can be compared with a mole plough. Even though not widely spread, mole ploughing for the drainage of sport pitches represents a similar interference with the turfgrass. For application of this technique, it is also important that the damage of the turf remains as low as possible. James et al. (James et al. 2007c) described that in case of mole-drains, reducing the slit-spacing reduces the time between the treatment and the restoring of playability. Therefore, the distance of the slits in the presented trials is only 250- 300 mm. The mole plough had a plough foot diameter of 50 mm and a working depth of 40 cm (James et al. 2007b). The mentioned authors recommend the width of the mole-plough leg to be smaller than 25 mm. The box coulter width of 15 mm is even below this value. The results of the visual scoring showed that the width of the box coulter did not significantly damage the turf.

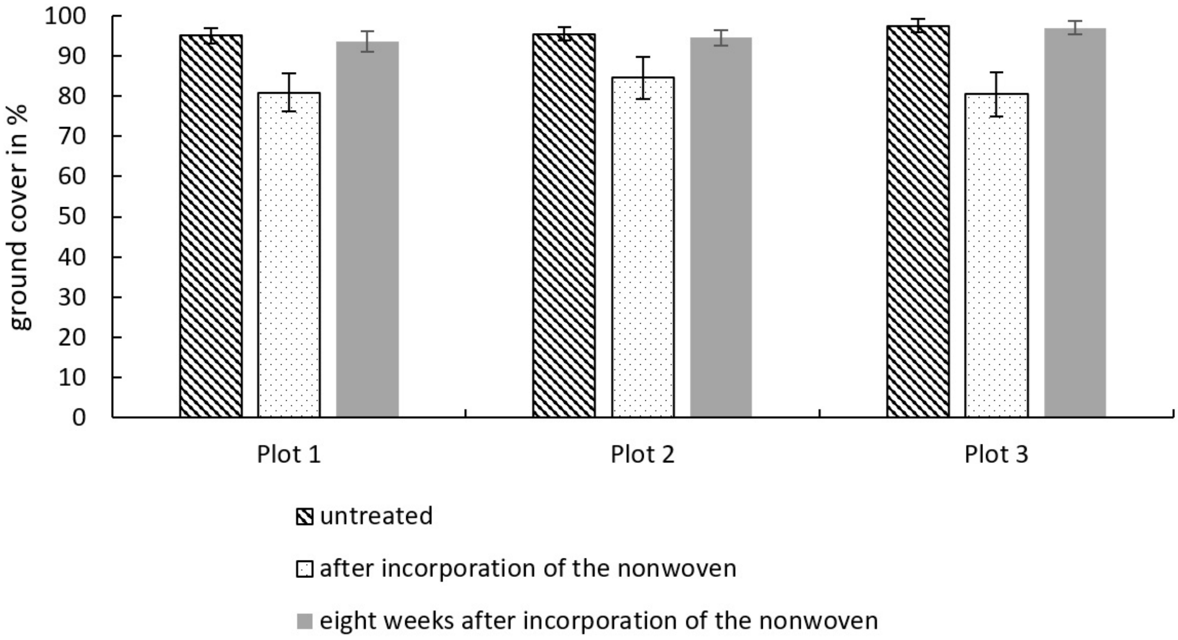

Figure 3-9: Mean ground cover (%) of plot 1, plot 2 and plot 3, untreated (three days before incorporation), after incorporation and eight weeks after incorporation of the nonwoven. Error bars shows the standard deviation.

3.4 Conclusions

This study describes the results of an evaluation of a newly developed device. The function of this device is to incorporate nonwovens into existing sport pitches. The results showed that the accuracy of the device's working depth meets the requirements. A lower accuracy was only observed at the beginning and the end of each plot. Since the plots were a little lower than the headland, the guide roller lifted the machine out of the ground. This, however, should not occur on sport pitches which normally only have a gradient of 0.5 % to 1 % (DIN 18035-4: Sportplätze - Teil 4: Rasenflächen 2018). At the time of the trials, the plots had a very low water content of 10.2 Vol.-%. Visual observation showed that the pressure roller restores the surface as desired. However, the penetration resistance indicates that the recompaction, especially under the lower edge of the vertical incorporated nonwoven, needs to be increased. This will avoid unevenness due to sinking of the surface. Under these test conditions no sinking was observed. The area with low penetration resistance showed an increase of air filled pores. Aeration is regularly performed on sports pitches to increase water permeability and supply the root zone with air (Aldous et al. 2001). Further research is needed to investigate this loosening in relation to the negative effects on the surface hardness. The turf was only damaged slightly, indicating that the chosen method of incorporation is appropriate. The cutting disc works properly since no clogging was observed at the box coulter. Clogging is the main reason for turf damage when regarding mole ploughing or the incorporation of sand slits (James et al. 2007a).

In addition to the presented study, more research is needed to investigate the benefits of nonwovens with regards to water use, turf cover, and wear. The evaluation of benefits of the nonwoven are still in research and will be published in the future. The presented pretests showed that the device mostly fulfills the requirements. In future research, the device needs to be tested under different soil conditions or working depths. Even applications to reduce soil erosion in native soils are imaginable. In this case the device would need to be reinforced and supplemented by an overload protection, due to the higher penetration resistance of native soils.

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4 The impact of incorporated nonwovens on the surface roughness of sport pitches[3]

Bastian Stürmer-Stephan, Jörg Morhard, Hans W. Griepentrog

Abstract

Sport pitches have to meet high requirements and are highly maintained. To reduce the costs, vertically incorporated biodegradable nonwoven should raise water from the drainage layer to the root zone. To incorporate the nonwoven in existing sport pitches, a device was developed. In the present study, the variation of the roughness after the incorporation of the nonwoven was evaluated. Different measurement methods for the roughness of sport pitches were evaluated. A low roughness is important for the players to avoid injuries to the athletes. A point laser, an ultrasonic sensor and a feeler wheel were tested for their suitability for measuring the surface roughness of turf sport pitches. The sensors were fixed to a measurement frame and pulled over the test plots before and after the incorporation. The feeler wheel showed the lowest standard deviation and a significant difference after incorporating the nonwoven. These results indicate that the feeler wheel is best suited to determine the effects of the incorporation device in relation to the surface. Comparing the results of the feeler wheel indicates that the developed device increases the roughness of the surface, but the effects are minor.

Keywords: roughness; sport pitch; sensors; nonwovens; surface

[3] Stürmer-Stephan, Bastian; Morhard, Jörg; Griepentrog, Hans W. (2022): The Impact of Incorporated Nonwovens on the Surface Roughness of Sport Pitches. In: Applied Sciences 12 (6), S. 2966.

4.1 Introduction

There are 35,993 sport pitches for soccer in Germany (Senatsverwaltung für Bildung, Jugend und Sport et al. 2002). Sport pitches are intensively used and highly maintained. Normally, they are constructed by a layer-by-layer structure, according to the German standard DIN 18035-4 (DIN 18035-4 2018). This structure consists of three layers as described from the top: rootzone, drainage and subgrade. The lowest layer is the subgrade, which consists of the existing subsoil. A drainage layer is installed when the subgrade is water impermeable. The turf grows on the root zone layer. The described construction method is comparable to that of the United States Golf Association (USGA), which is used on golf courses in the United States of America. The USGA drainage layer is made of gravel with a particle size distribution of 65% between 6.4 and 9.5 mm. The high water permeability is necessary to drain excess water from sports surfaces. At the same time, supplying turf grasses with sufficient water is a major challenge for the planning and construction of sports pitches (Adams 1986). Therefore, artificial irrigation is necessary.

To reduce the irrigation costs of a sport pitch built according to DIN 18035-4, an improvement of the standard construction method was developed (Maschler et al. 2019). A vertically incorporated biodegradable nonwoven should raise water from the drainage layer to the root zone. To vertically incorporate the nonwoven in existing sport pitches, a device was developed that precuts the turf vertically, opens a slit, places the nonwoven vertically into the slit, closes it up and finally compacts the root area again (Stürmer-Stephan 2021). This device literally causes a change in the surface due to the high interference with the turf.

A low roughness of the surface is important for the playability of the sport pitch. If the surface profile is not level, the players can be injured and the desired mowing height cannot be fulfilled. In addition, an increased roughness is associated with a decreasing ball rolling length. Roughness is defined by the deviation from the ideal surface of the object. On sport pitches, the roughness is the deviation of the profile from an ideally leveled sport surface. However, reviewing literature showed no significant research on the surface roughness for sport pitches with natural turf. This does not apply to artificial turf. Here, the roughness of the surface is of high importance for the playability and the injury rate in sports (Dixon et al. 2015; Tay et al. 2017).

Much research exists on the measurement of road or field profiles. Description and classification of road surface profiles are standardized by ISO 8608 (ISO 8608 2016). According to this standard, the fast Fourier analysis is used to calculate the power spectral density. This power spectral density is used to classify the roughness of a road in eight classes, but the standard does not specify an explicit measurement method (Loprencipe and Zoccali 2017). The power spectral density evaluation is strongly dependent on the measurement method and the measurement frequency (Podulka 2021). The international roughness index was established by the World Bank and is calculated by using a measured profile. It is smoothed by a quarter-car model of a so-called golden car with a speed of 80 km h^{-1} (Sayers 1995). Both indexes are used to assess the riding quality on road pavements. The presented study deals with the roughness of sport pitches that can be better compared to agricultural areas rather than to roads. The power spectral density according to ISO 8606 is even used to describe country roads or grass fields to evaluate the fatigue life of agricultural machinery (Paraforos 2016). However, according to the German standard DIN 18035-4, the evenness of a sport pitch is measured with a 4 m long leveling bar and a measuring wedge with a measurement resolution of 1 mm (DIN 18035-4 2018). The unevenness of the sports pitch surface must be less than 20 mm over a length of 4 m (DIN 18035-4 2018). This method is normally used for the acceptance of the work performed on a sport pitch, but not in research.

In laboratory studies, the roughness of soil surfaces is often measured with a pin meter or a roller chain, when using contact devices (Jester and Klik 2005; Raine and Eberhard 2004). Noncontact measurements of soil surfaces are performed by photometers, infrared sensors, ultrasonic sensors, laser technics and satellite radar (Jester and Klik 2005). The major disadvantage of the first-mentioned contacting instruments is the deformation of the soil surface during the measurement. Noncontact measurements are widely used, but they require more technical and expensive equipment. Furthermore, the resolution accuracy of the height in airborne measurement methods is not sufficient, or measurement errors occur due to the turf (Turner et al. 2014). In the present study, the surface of an experimental sport pitch needs to be evaluated. Because a standard soccer field has a size of 4,000 to 10,000 m^2, the measurement would be time-consuming if using a pin meter. Therefore, in the present study, the measurements were performed by a measurement frame. It carries contact and noncontact sensors. A feeler wheel, an ultrasonic sensor and a laser pointer were attached to the measurement frame. The use of laser measurement methods with static apparatus for determining soil surfaces is widely known, but the use on turf-covered areas by using continuous measurement methods is a new approach (Bertuzzi et al. 1990).

There are many indexes or methods to compare the roughness of a soil surface. Following Gadelmawla et al. (Gadelmawla et al. 2002), the indices are divided into amplitude, spacing and hybrid parameters. The amplitude parameter describes the vertical characteristics and the spacing parameters measure the horizontal characteristics of the surface deviations. The hybrid parameters are a combination of both (Gadelmawla et al. 2002). Amplitude parameters are the most common. The surface roughness of turf sports fields is described by the parameter of maximum roughness. This value is based on the depth gauge. It is the maximum deviation at one point from a straight line formed by two maximum points of the measured profile. If several measurements are taken on one sports field, the arithmetic mean of this maximum roughness is used to describe the evenness (DIN 18035-4 2018). Therefore, the root mean square was used in the presented study to describe the changes of roughness on the experimental sport pitch. The main purpose of the present study was to evaluate the impact of incorporating a nonwoven into a sport pitch in relation to the surface roughness.

4.2 Materials and methods

In the present study, the variation of the roughness after the incorporation of the nonwoven was evaluated. Additionally, this publication evaluates different measurement methods for the roughness of sport pitches. To compare the different measurement methods, a rectangular measurement frame was used (Figure 4-1). Its dimensions were 1600 mm in width and 1800 mm in length. It was made of square steel tubes with dimensions of 40 × 40 mm and consists mainly of four crossbars connected by longitudinal beams. The measurement frame had four free rotating wheels for driving. The wheels were continuously height-adjustable in order to adjust the measurement frame to the working distance of the sensors. The internal orientation of the measurement frame was measured by a VN-100 inertial measurement unit (manufactured by VectorNav Technologies, Dallas, USA). The measurement resolution of the sensor is 0.05°, with repeatability equal to 0.2°. For a dynamic determination of pitch and roll, the deviation from the root mean square is 1°. The inertial measurement unit was attached to the rear crossbar of the measurement frame.

The external orientation of the measurement frame was determined with an M900 retroreflecting prism and a highly accurate robotic landscape surveying instrument (SPS930) (manufactured by Trimble, Sunnyvale, CA, USA). The retroreflecting triple prism was fixed to the third crossbar at a height of 430 mm above the measurement frame to plot the coordinates in a Cartesian coordinate system. By fusing the data of the inertial measurement unit and the Cartesian coordinates, the position of the measurement frame was calculated. Because the distances between the measurement frame and the sensors were known, the measured points could be integrated into the same coordinate system.

Three sensors were fixed on the measurement frame. The first one, pointing in the direction of travel, was a UM30-212113 ultrasonic sensor (manufactured by SICK AG, Waldkirch, Germany), with a frequency of 400 kHz. It can measure natural objects within an operating range of 65 to 350 mm. The accuracy is ±1 %, with a resolution of more than 0.18 mm. The measured distance is exported via an analog output of 0 to 10 V with a 12-bit resolution. The measured distance was converted by an analog–digital transmitter with 16-bit resolution (RedLab 1608FS-PLUS) (manufactured by Meilhaus Electronic, Alling, Germany). The second sensor in the direction of travel was a long-range DT-500 distance sensor (manufactured by SICK AG, Waldkirch, Germany) with an operating range of 80 to 15,000 mm. It has a 12-bit resolution and an accuracy of ±3 mm. To reduce measurement errors, the laser beam was protected against sunlight with a tube.

Afterward, a feeler wheel was installed to measure the contact surface. The feeler wheel had a weight of 6100 g and an inflated rubber tire with a diameter of 280 mm.

The tire had a width of 65 mm. Therefore, no deformation of the surface was expected and observed. Due to its weight, the feeler wheel follows the contour of the surface and pushes down the grass. The feeler wheel was mounted on a quadratic steel tube. This tube was guided by a larger quadratic square tube in height and could move without friction. The movements of the feeler wheel were measured from the frame by a midrange distance sensor. Because a reflector was installed on the feeler wheel, the distance sensor reached a resolution of 1 mm and an accuracy of ±10 mm. For data acquisition, a software program based on Microsoft C++ was used (Paraforos 2016). In postprocessing, the cubic spline interpolation routine in MATLAB (R2018b Update 2 Version 9.5.0.1033004) was used to synchronize the sensor data with the timestamps of the total station. By fusing the Cartesian coordinates of the measurement frame with the sensor data, the coordinates of the surface can be calculated. For the validation of the measuring setup, a wooden trapezoidal bump fixed to a level ground was measured. It had a height of 40 mm and a slope of 45 degrees on both sides. Then, the calculated height profile was compared with the height profile of the trapezoidal bump.

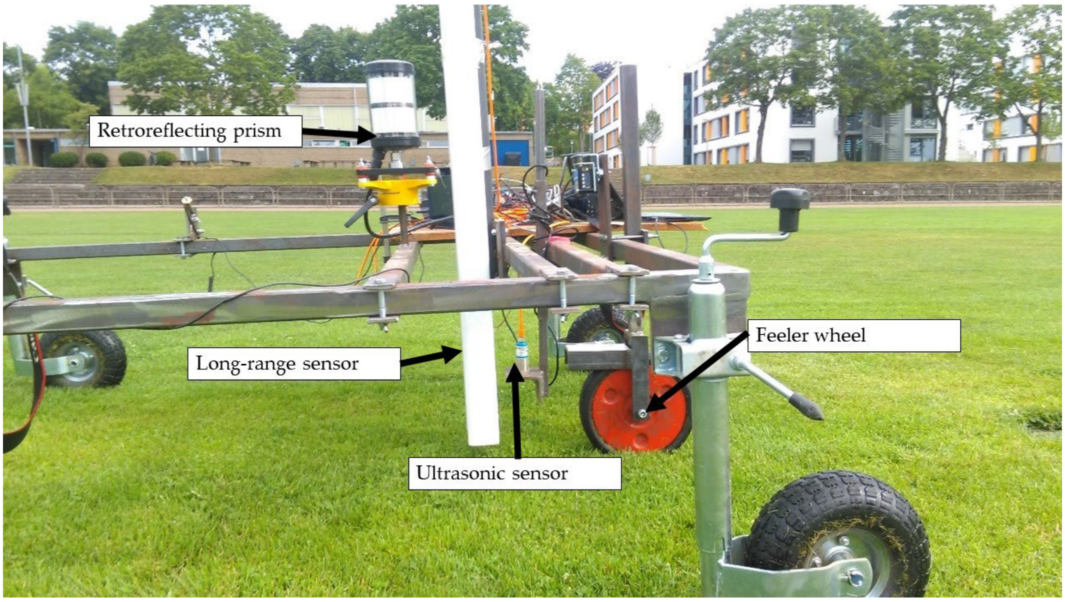

Figure 4-1: The measurement frame with the retroreflecting prism and the ultrasonic sensor, the feeler wheel and the long-range sensor. The retroreflecting prism has a distance measurement accuracy of ±(4 mm + 2 ppm). The ultrasonic sensor has an accuracy of ±1%, with a resolution of more than 0.18 mm. The long-range sensor has an accuracy of ±3 mm. The displacement of the feeler wheel according to the measurement frame was measured with an accuracy of ±10 mm by a midrange distance sensor.

4.2.1 Description of the trial area

To measure the changes in the roughness of a sport pitch when incorporating a nonwoven, three plots were built on the fields of the experimental station Heidfeldhof at the University of Hohenheim (Figure 4-2). The plots were constructed following the German standard DIN 18035-4, with a 120 mm high drainage layer and a 130 mm high root zone layer. The plots were 4 m wide and 11 m long. The turf was seeded in

October 2018 and mowed with a cutting height of 30 mm. The mowing was performed before the measurements, to avoid measurement errors due to the turf. The plots are surrounded by headland areas of natural soil, only seeded with turf. The plots were numbered from 1 to 3 ascending northwards. The terrain had a slope towards the north. In each of these plots, seven tracks of biodegradable nonwoven were incorporated vertically on August 26th, 2019. The dimensions of the incorporated nonwoven were 150 mm times 5 mm (Figure 4-3). For this purpose, a machine was developed at the University of Hohenheim. It precuts the turf, forms a slit with a box colter, inserting the nonwoven into the slit. Finally, a pressure roller reconsolidates the surface. To evaluate the impact of the device on the surface, the roughness was measured before and after incorporating the nonwoven.

Figure 4-2: Aerial picture of the three plots used for the trials.

Figure 4-3: The vertically incorporated biodegradable nonwoven in a plot.

4.2.2 Method of measurement

Ten measurement tracks were carried out on each plot with the measurement frame right-angled to the working direction of the device. The measurement tracks were spaced 0.7 m apart and 4 m long. In addition, four measurement tracks were measured in the same direction as the working direction of the device at a distance of 0.7 m from each other and a length of 11 m. The measurement frame was pulled by hand at a speed of about 500 m h−1. The results presented showed the data collected by the rectangular and the longitudinal measurement tracks. Measurements were conducted on 25 August 2019 and 26 August 2019 after incorporating the nonwoven.

4.2.3 Postprocessing of the data

The fused coordinates of the measurement frame were used to calculate the profiles of the surface for each sensor. First, the distance between the measured points was calculated according to the plane. This raster was performed with R Studio (Version 1.1.463). Afterward, the resulting profile was used for statistical analyses. According to Liu et al. 2018 and Gadelmawla et al. 2002, the root mean square roughness was calculated and used for analysis. The authors used the arithmetic mean line to calculate roughness. In the present study, the root mean square (RMS) is calculated with a linear regression because the plots had a slope. First, a linear regression was calculated by least-square method, and then the root mean square of the residuals was calculated and presented in the results. For the validation of the sensor frame, the RMS error was calculated following Equation (1):

$$RMS_{error} = \sqrt{\frac{\sum_{i=1}^{n}(z_{r,i}-z_{tr,i})2}{n}} . \quad (1)$$

where $z_{r,i}$ is the measured profile height, $z_{tr,i}$the true profile height of the trapezoidal bump at the position *I* and *n* is the number of measurement points. The RMS_{error} was only calculated at those positions where the trapezoidal bump was located.

The mean $RMS_{roughness}$ for the roughness of the measured profiles was calculated using the following equation:

$$RMS_{roughness} = \sqrt{\frac{\sum_{t=1}^{n}(\hat{z}_t-z_t)2}{n}} . \quad (2)$$

The $RMS_{roughness}$ was calculated with $\hat{z}_t$, the estimated profile height of the linear regression, and z_t, the measured profile height at the position *t*. The number of the measured point is presented as *n*. The results presented were calculated from *n* = 750 measurement points. The arithmetic means and the standard deviation of the $RMS_{roughness}$ were calculated for the 14 measurement tracks of each of the three plots.

4.3 Results

For validation of the sensor frame, the measured profiles and the real profile of the trapezoidal bump are presented (Figure 4-4). The means of the measurements (*n* = 5) recorded by the feeler wheel, the distance sensor and the ultrasonic sensor are shown. Using Eq. (1), the RMS_{error} was calculated for the location of the trapezoidal bump. The RMS_{error} was 1.8 mm for the profile measured by the feeler wheel. The results of the distance sensor showed an RMS_{error} of 7.7 mm according to the profile of the trapezoidal bump. The ultrasonic sensor measured the highest variation to the real profile of the trapezoidal bump, with an RMS_{error} of 9.9 mm. The ultrasonic sensor showed a high amount of variation due to the low reflection. However, the error was lower than 10 mm. The presented profiles are the results of one measuring track of the first plot measured by the feeler wheel before and after the incorporation of the nonwoven (Figure 4-5). The changes in the roughness are obviously lower than 20 mm, and a direction of the variation is not visible in the presented data.

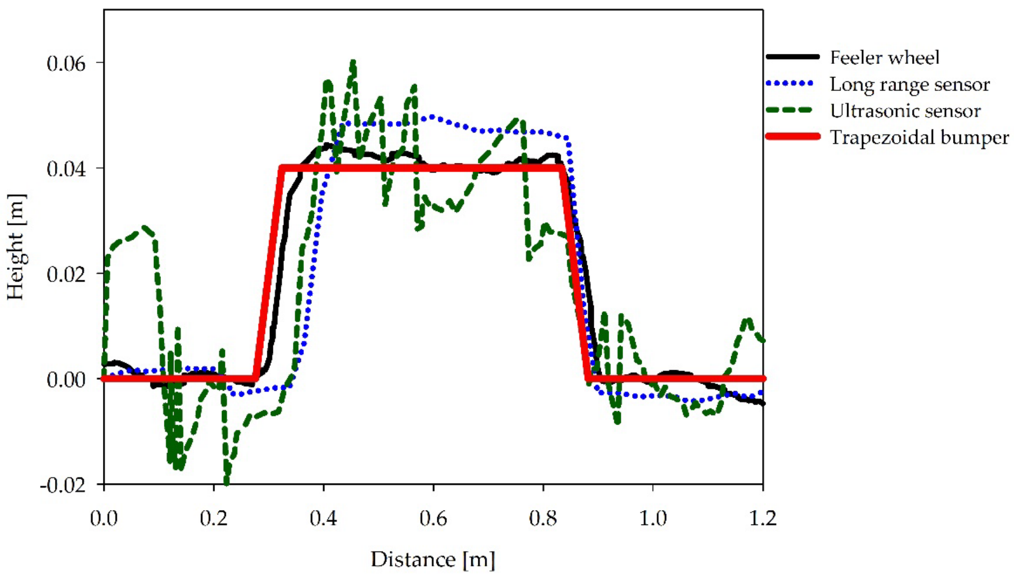

Figure 4-4: The profile height in meters measured by the feeler wheel, the long-range sensor and the ultrasonic sensor in comparison with the real profile of the trapezoidal bump. The profile height is presented in relation to the driven distance in meters.

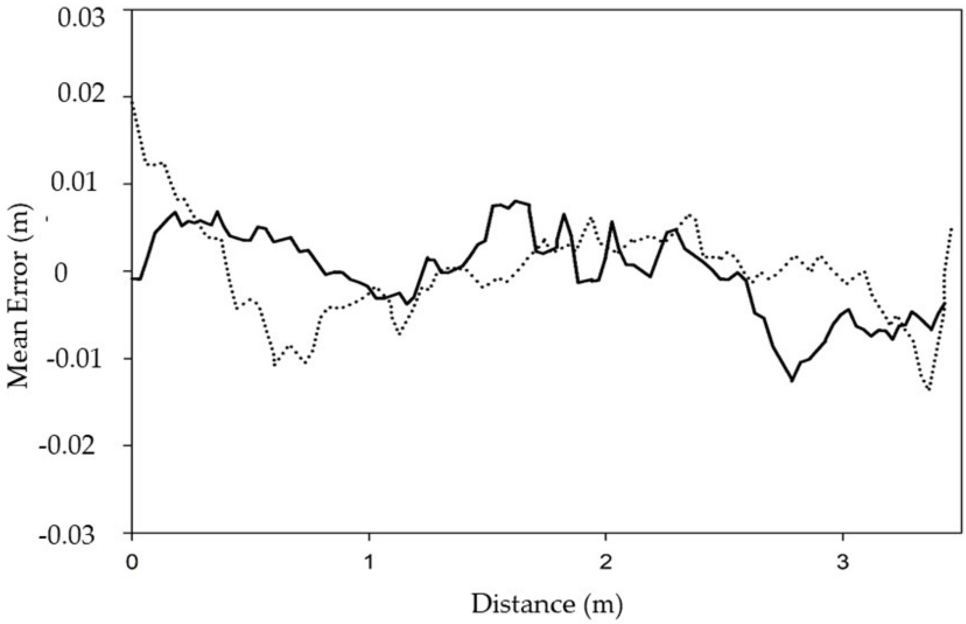

Figure 4-5: Exemplary variation profile of a measurement track of plot 1 before and after the incorporation of the nonwoven. Profile was measured with the feeler wheel.

4.3.1 Impact of incorporating the nonwoven in the trial area

In the presented study, the impact of incorporating a nonwoven in relation to the surface roughness was also investigated. Figure 4-6 presents the variation in surface roughness caused by incorporation. The $RMS_{roughness}$ calculated according to Equation (2) was used to compare the results of the feeler wheel. Each bar of the bar chart presents the mean $RMS_{roughness}$ of 14 replications measured on each of the three plots. The error bars indicate a standard deviation of the $RMS_{roughness}$ for the 14 replications. The black-colored bar describes the $RMS_{roughness}$ before the incorporation of the nonwoven, whereas the grey bar stands for the mean $RMS_{roughness}$ after the incorporation. A paired Tukey test for the roughness of all replications was performed. The p-value of 0.0375 indicates a significant change in the mean values of the $RMS_{roughness}$ after incorporation. Figure 4-6 allows the conclusion to be drawn that the surface roughness has been increased, affected by the installation of the nonwoven. For example, the $RMS_{roughness}$ in plot 3 increased from 0.008 to 0.011 due to the installation of the fleece. The high standard deviation in the repetitions indicates that the measured plots have a high heterogeneity of surface roughness. Figure 4-6 shows that the values for $RMS_{roughness}$ in plot 1 are lower than those in plots 2 and 3.

Data for the roughness of the three plots measured with the long-range sensor are presented in Figure 4-7. The results are shown as the mean $RMS_{roughness}$ before and after the incorporation of the nonwoven, following Equation (2). Figure 4-7 describes that the incorporation of the nonwoven has increased the roughness of the surface in plot 1 and plot 2. Statistics performed by a paired Tukey test describe no significant difference between the means of all measurements before and after the incorporation. This is mainly caused by the high standard deviation of the first plot. The high standard deviation may result from measurement errors due to the reflection of the laser beam on the turf. From the calculated mean $RMS_{roughness}$ presented in Figure 4-8 it is obvious that the profile measured by the ultrasonic sensor detects no changes in the roughness. A day before the incorporation of the nonwoven, the roughness was about 10 to 12 mm, presented as $RMS_{roughness}$. After the device had incorporated the nonwoven into the sport pitch, the surface shows a higher roughness with an increase of about 3 mm. The standard deviation is much lower compared to the measurements performed with the long-range sensor. The calculated *p*-value for the paired Tukey test is about $p = 0.24$ when comparing the means of the measurements performed before and after the treatment. As a result, no significant changes in the surface roughness can be detected. The ultrasonic sensor has a resolution of 0.18 mm, but due to the vegetation on the sport pitch, it is possible that the measurement errors increased. This assumption can also be transferred to the long-range sensor. In addition, the ultrasonic sensor covers a larger area, increasing the errors of the measurements.

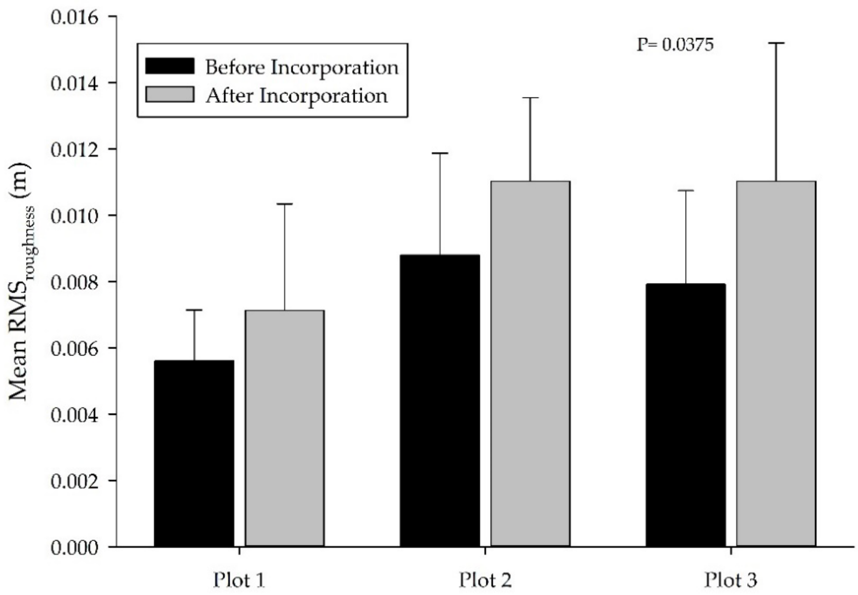

Figure 4-6: Arithmetic mean $RMS_{roughness}$ (m) of the measured profile before and after the incorporation of the nonwoven. *n* = 14. The measurement was performed by the feeler wheel. The error bar is the standard deviation. The *p*-value shows the paired Tukey test for mean $RMS_{roughness}$ before and after the incorporation calculated for all three plots.

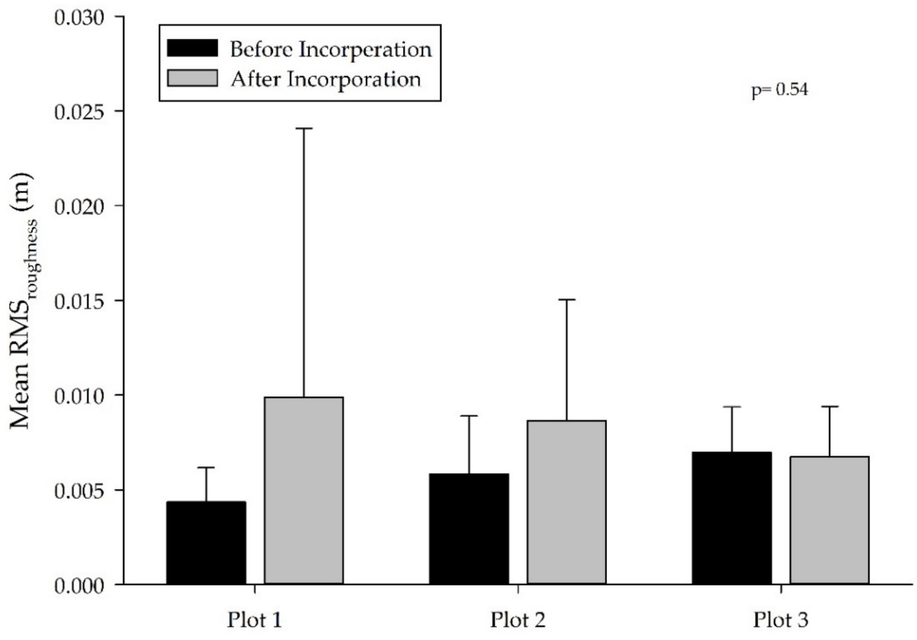

Figure 4-7: Arithmetic mean $RMS_{roughness}$ (m) of the measured profile before and after the incorporation of the nonwoven. *n* = 14. The measurement was performed by a long-range sensor. The error bar is the standard deviation. The *p*-value shows the paired Tukey test for mean $RMS_{roughness}$ before and after the incorporation calculated for all three plots.

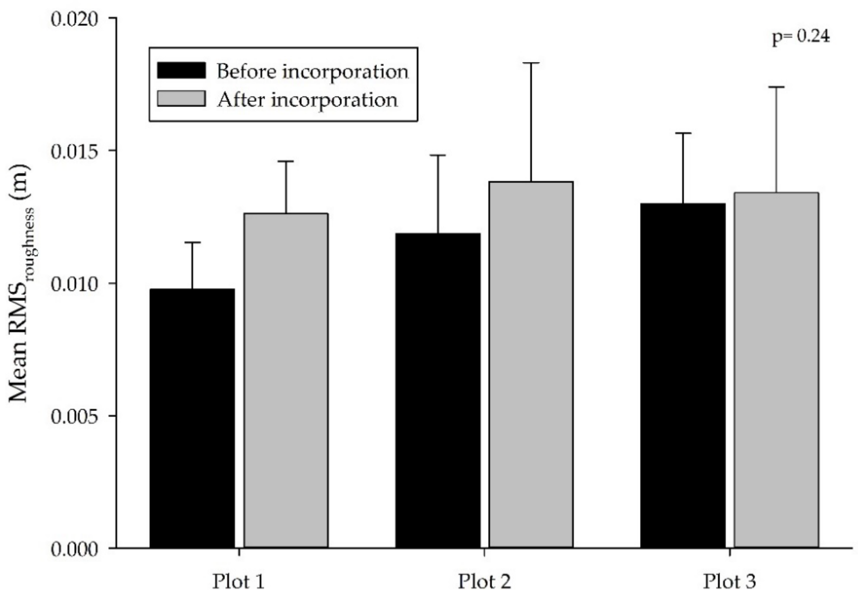

Figure 4-8: Arithmetic mean $RMS_{roughness}$ (m) of the measured profile before and after the incorporation of the nonwoven. The measurement was performed by ultrasonic sensor. The error bar shows the standard deviation. *n* = 14. The *p*-value shows the paired Tukey test for mean $RMS_{roughness}$ before and after the incorporation calculated for all three plots.

4.4 Discussion

In this section, the results are analyzed and discussed. Three sensors were compared during the experiment. The feeler wheel showed the lowest standard deviation and a significant difference after incorporating the nonwoven. These results indicate that the feeler wheel is best suited to determine the effects of the incorporation device in relation to the surface. The feeler wheel weighs 6100 g and therefore avoids measurement errors due to vegetation because it presses down the grass leaves. However, the weight is low enough that no compaction of the soil surface occurs. This fact is evident from the significant difference between the treatments. The measurements of the ultrasonic and long-range sensors showed no significant difference and a high standard deviation. In particular, the long-range sensor showed high scattering in the values measured on the first plot (Figure 4-5). The reason for this could be that the leaf mass of the grasses deflects the laser beam. This ultrasonic sensor had already been tested to measure the working quality of tillage implements such as the chisel plow (Robichaud and Molna 1990) The circular measurement area of the ultrasonic sensor has a suitable size. However, a soil surface is significantly rougher than the tested sports surface. Still, a significant increase in the sports turf surface is evident as a result of the incorporation process. This is mainly due to the opening of the soil with the aid of the colter, which pushes the soil open and cannot be completely leveled by the pressure rollers. In the same way, the cutting of the turf cover has an influence on the surface change.

The measured profiles were compared to the $RMS_{roughness}$. Considering the measurement results of the feeler wheel, it is evident that there is a significant increase in roughness. The question now arises as to how this change is to be assessed. In the German standard DIN 18035-4, a maximum deviation of 30 mm at 4 m measuring bar length is specified. Since this deviation is only measured at one point, the $RMS_{roughness}$ according to Eq. (2) is equal to the root of 30 mm. The maximum roughness is about 5.4 mm. According to the results measured before the incorporation, the roughness is higher than the standard. However, the difficulty is the comparability of the two measuring methods. In addition, the vegetation causes high roughness due to the uneven height of the material build-up caused by the turf (e.g., by lawn thatch (Martin et al. 2002)). To solve this problem, the turf could have been groomed and top-dressed before the trials started. However, to investigate the influence of the device incorporating the nonwoven, the difference between before and after installation is crucial. If comparing the results of the feeler wheel, the difference is significant, but it is less than 5 mm. This indicates that the developed device increases the roughness of the surface. The measurement results indicate that it is necessary to improve the incorporation device and, for example, to equip it with a heavy pressure roller.

4.5 Conclusion

A low roughness is one of the central requirements for the good quality of sport pitches. Therefore, it is important to develop maintenance equipment that does not cause any negative changes to the surface. There has been little research on the roughness of turf sports pitches so far. A measurement frame was used to determine the surface roughness before and after the vertical incorporation of a nonwoven in three plots, built according to the German standard DIN 18035-4. In common research, a leveling bar is used for measuring surface roughness (Bartlett et al. 2009). Nevertheless, from the presented studies, the following remarks can be provided:

1. The validation of the measurement frame showed that the root mean square error between the real surface and the measured surface was below 10 mm. Therefore, the measurement method was considered suitable.

2. The measurements performed by the feeler wheel showed a significant increase in roughness after the incorporation. The results indicate that only the feeler wheel can be used to continuously determine the roughness of a sport pitch because a low standard deviation was observed.

3. The device for incorporation of the nonwoven in existing sport pitches must be improved to avoid increasing the roughness of the turf surface.

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5 General discussion

In consideration of the climate change, the construction of a new sports field must be adapted accordingly. Decision makers needs to determine the dimension and the physical properties of the root-zone mix, in terms of the irrigation demands. The developed model relies on the precipitation measured by a weather station and the estimated potential evapotranspiration. That allows to find a cost optimum between the substrate dimension and the irrigation costs in a given depreciation period under local weather conditions. This is an important economic factor, because a sandy root zone mix is twice as expensive than a top soil root zone (Mark 2002). In order to adapt a planned sports field to a given location, it is necessary to rely on water balances for a specified substrate. If possible, a low-cost lysimeter can be installed before construction begins. The lysimeter must be filled with the desired substrate and a chosen turfgrass type to improve the developed models and to help the decision makers. (Wherley et al. 2009) This allows the cost optimum to be better adjusted with the model and improve the decision support system. Using substrates with a superior available soil water holding capacity could be an alternative to avoid higher substrate layers. Such substrates may, for example, consist of porous aggregates like lava or zeolite (Ferguson et al. 1986; Nus und Brauen 1991). These components are light weighted and can be transported over longer distances to the construction site. In order to keep the transport costs low, these components can be mixed on-site with structural components like sand from closer pits. The results of this work show that irrigation costs clearly depend on the design of the sports field. This might lead to higher construction costs, but to considerable savings in the long term. Modern turfgrass sports field substrates also have fairly good water drainage during heavy rain and downpours, allowing longer periods of use. That reduce the costs per hour of use. (Baird 2005; Cereti et al. 2004) The presented work still comes with a number of uncertain factors. The work shows that the simulation-based technical design of sports field comes with a significant potential to find an economical optimum between construction and irrigation costs. In order to be easily adopted by construction engineers, the developed model was implemented in Microsoft® Excel. Other authors use Neural Network to predict sports field cost. (Juszczyk et al. 2019) Whereas this Neural Network does not perform any optimization routine based on weather conditions. The presented work uses weather conditions, but just a reduced water balance approach. This approach uses water holding capacity as a parameter for water availability. But it is not considered whether the water is also available to roots of the plants (Huang 2008b). Because the model does not take into account the shallow rooting that often occurs on sports fields (Lin 1985; Huang 2008a; Parr, T. W., R. Cox, and R. A. Plant 1984). So, an increase in root zone depth does not always mean that the roots of the plants can reach the water table.

Another attempt to adapt already existing sports fields to climate change, is the incorporation of a nonwoven into the root zone. The nonwoven needs to be incorporated in a uniform depth of 180 mm under the surface of a sports field. Due to this, a new device was developed and evaluated. The device opens the turf, inserts the nonwoven and then recompacts the surface. Trenchers used for sand slitting work with actively driven slitting discs or a milling chain (Michael Lee Lansdale 1998). But due to a massive intervention, the surface is disturbed and the turf needs a long regeneration time. During this period the sports field cannot be used for playing. Without any actively driving trenching component the presented device, reduces the hours of disruption in comparison to a trencher. The evaluation of the developed device showed that the deviation of the working depth is less than +-20 mm. Even when the plots have a very low water content, the device was able to penetrate deep enough into the soil. Visual observation showed that the pressure roller restores the surface as desired, especially, when comparing the results with deep drilling or the incorporation of sand (Linde et al. 2022). However, the penetration resistance indicates that the recompaction, especially, under the lower edge of the vertical incorporated nonwoven, needs to be increased to avoid settlements. This behavior was observed under different soil moisture contents on sports fields with near-ground construction after filling slits with sand (Fisher und Ede 1974). If no settlement occurs, the loosening of the root zone may have positive effects on the gas exchange, like aeration. Aeration is a standard maintenance technique for sports fields (Atkinson et al. 2012; Desoky 2017). But in addition, an increase in roughness can occur due to the degradation of the nonwoven. Improving the machine could be achieved by increasing its weight and transferring the weight to the pressure roller. The challenge is the fact, that the coulter of the device does not loosen soil for recompaction, after incorporating the nonwoven. The furrows of the developed device can be recompacted more effectively by using two pressure roller, attached V-shaped (Dugato und Palma 2018). It must be verified that the two pressure rollers do not cause ridge formation, as is the case with seed drills. To avoid ridge formation, wider pressure rollers would be possible. However, these have a larger contact area, which requires a higher weight of the machine. The cutting disc of the developed device works satisfactorily, since no clogging was observed at the box coulter. The reason for this could be the large diameter of the cutting disc of 580 mm. Tests on straw have shown that a larger diameter has a positive effect on the tensile forces and the cut. (Choi und Erbach 1986)

One of the main requirements for a sports field with natural turf is a marginal surface roughness. Therefore, it is important to develop equipment that does not cause changes in the evenness of the surface. In practice, the roughness of a sports field is evaluated with a 4 m long leveling bar and a measuring wedge (DIN 18035-4 2018). This is time-consuming and therefore expensive. The developed measurement frame works with four different sensors to measure the surface profile. A similar measurement frame was developed for the measurement of the surface of country roads. (Paraforos et al. 2016) The results obtained with a feeler wheel showed a negative effect of the device on surface roughness. However, the effects of other cultivation machines to the turf surface, e.g. mole drainage, were never evaluated with the precision of the sensors used in the presented work (James et al. 2007). To decrease the effect to the surface, a vibrator could be attached to the box coulter of the device. Oscillation results in a better displacement of the soil to the bottom and th side of the furrow (Niyamapa and Salokhe 2000). In addition to roughness, it is also important that the nonwoven does not protrude from the surface. This would be a potential tripping hazard for the players. The measurements have shown that the deviation of the working depth is lower than 10 mm. It was also possible to determine that the device incorporates the nonwoven rather deeper than shallower. It can be concluded that the adjustable working width of the pressure roller shows good results in setting the working depth.

5.1 Outlook

This work deals with two approaches to optimize sports fields to climate change. The first approach is to develop an economic decision model regarding water costs and the dimension of the rootzone. The model takes into account weather records and the water holding capacity of the substrates used in the construction of sports fields. For further research, these models must be evaluated in field trials. This can be done by lysimeters. These should be installed near to sports fields and set up with a sand-based rootzone including a drainage layer. When a sports field already exists, organic or mineral additives can be incorporated in the layer with machines. As future work, the effects of the additives in rootzones could be tested and the results can be taken into account in the model (Chong and Ok 2006; Hejduk et al. 2012). The device of the present work needs to be improved in relation to the surface roughness, which was affected significantly. The presented device was developed without actively driven components. There are devices on the market that incorporate sand or drainage tubes into the root zone or the soil. These devices have vibrating box coulters. A direct comparison with the developed machine in terms of tractive force and work quality should be carried out in future studies. The evaluation of the nonwoven was not part of this research work. Therefore, it needs to be evaluated if the nonwoven has a significant effect on the water transport to the roots of turfgrasses on sports field. First experiments showed a positive influence of the nonwoven, because laboratory trials showed the capillary rise of water in the root zone. The hydraulic properties of nonwoven and experiments done for sub surface irrigation support this hypothesis (Iryo and Rowe 2003; Abidin et al. 2014). The success of such a nonwoven must also be evaluated from an economic point of view. For this purpose, the costs for an entire sports field must be recorded and the service life must be considered. Furthermore, the profitability of the nonwoven depends on the irrigation costs. Maybe other approaches are more economic. For example, the seeding of turfgrass species or varieties that are drought tolerant (Fu et al. 2004; Hatfield 2017). With increasing temperatures, it would be feasible to grow warm season grasses, in certain areas of Europe which require less irrigation in summer (Luca et al. 2008). But warm season grasses become dormant in winter and have a lower freeze tolerance than cold season grasses. But breeding grasses for drought tolerance is also an important component in reducing water consumption (Patton and Reicher 2007).

In future, not only sports field must be adapted to climate change, but also the impact of the sports field on the environment must be reduced. Sports fields are often maintained with fuel-powered mowers. In the future, electric robotic mowers will be used more and more frequently. This will reduce direct emissions, especially if the electricity originates from renewable energies (Saidani et al. 2021). Robotic mowers can reduce the need for fertilizer on the sports field, as the grass clippings are mineralized and made available to the grasses again. This reduction in fertilizers can reduce the carbon footprint of the sports turf in the future (Itten et al. 2020). In the future, it is expected that the use of crop protection products will be severely restricted. To ensure that the quality of sports fields remains the same, alternatives such as mechanical or automated weed control must be investigate. All these challenges must be met in the future. But sports fields with natural turf are important not only for the urban climate, but also for the health of the population (An et al. 2022).

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6 Summary

Due to climate change and the need to save water, water consumption must be reduced not only in agriculture but also in urban areas. There are 55,072 sports fields in Germany that have to be irrigated in summer. In order to reduce the amount of irrigation, two approaches were researched and discussed in this thesis. The first approach is to adapt new sports fields to the local weather conditions. This approach is a decision support system, based on a model. The input variables are recorded weather data from the German Weather Service for the location where the new sports field is to be built, the hydrological properties of the substrates, and the expected costs. An optimized dimensioning of the rootzone layer is calculated by an EA solver of Microsoft Excel. This thickness of the layer can be used for the construction project. This was calculated exemplary for 3 locations. The presented model needs to be further evaluated through field trials. For existing sports fields, the root zone layer can only be changed with great effort. In this case, a biodegradable nonwoven can be installed in an existing sports field with drainage layer structure. This nonwoven transport water from the deeper drainage layer into the root zone of the turf through the capillaries, so that the water is available to the turf. To achieve this function, the 150 mm wide nonwoven must be installed vertically at a depth of 170 mm +-20 mm. During installation, the ground cover must not be reduced and the roughness of the surface must not be increased. In the present work, a device is presented, that cuts the turf, opens a furrow, incorporates the nonwoven and then closes the furrow. The device is mounted on the tractor and consists of a height guide, a cutting disc, a box coulter and a pressure roller. The device was tested on three plots with a layer structure in Stuttgart. The cutting disc works properly because no clogging was observed. A measurement frame equipped with an ultrasonic sensor, a laser range finder and a feeler wheel determined the surface roughness before and after incorporating the nonwoven. The results showed a significant increase in roughness. In order to reduce the negative impact to the ground surface, it would be possible to increase the ballasting of the device. However, harmful soil compaction must be avoided. The uniform working depth of the developed device was determined with a tachymeter and showed a deviation from the nominal depth of less than 20 mm. The results show that this meets the requirements for the device. Ground cover was measured before and after installing the nonwoven. The turf damage was less than 15 % of the ground cover, which meets the playability requirements. Reconsolidation was determined by penetrologger and evaluated in profile. The soil recompaction, measured as penetration resistance, was similar to the status quo, except in the area close to the nonwoven, where the recompaction failed. The furrows of the developed device can be recompacted more effectively by using two pressure roller, attached V-shaped. But it must be verified that the two pressure rollers do not cause ridge formation, as is the case with seed drills. Overall, the performance of the device can be considered positive, but improvements are still needed to improve reconsolidation. These improvements can be verified in future investigations. At the same time, the effectiveness of the nonwoven must be evaluated in the future. Preliminary tests have shown that the capillary action is sufficient to transport water from the drainage layer to the root zone.

7 Zusammenfassung

Aufgrund des Klimawandels und der Notwendigkeit, Wasser zu sparen, muss der Wasserverbrauch nicht nur in der Landwirtschaft, sondern auch in städtischen Gebieten reduziert werden. In Deutschland gibt es 55.072 Sportplätze, die im Sommer bewässert werden müssen. Um die Bewässerungsmenge zu reduzieren, wurden in dieser Arbeit zwei Ansätze erforscht und diskutiert. Der erste Ansatz ist für neu angelegte Rasensportplätze konzipiert und basiert auf einer Modellierung des erforderlichen Rasentragschichtaufbaus für einen Rasensportplatz. Die Eingangsgrößen sind aufgezeichnete Wetterdaten des Deutschen Wetterdienstes für den Standort des neu zu errichtenden Sportplatz, die hydrologischen Eigenschaften der Substrate und die zu erwartenden Kosten. Eine optimierte Dimensionierung der Rasentragschichtdicke wird mit einem EA-Solver von Microsoft Excel berechnet. Diese Dimensionierung kann für das Bauprojekt verwendet werden. Die vorgestellte Modellierung muss in zukünftigen Untersuchungen durch Feldversuche evaluiert werden. Bei bestehenden Rasenspielfeldern kann die Rasentragschicht nur mit großem Aufwand verändert werden. Für diesen Fall wird ein biologisch abbaubares Vlies in einen bestehenden Sportplatz mit Drainageschichtaufbau eingebaut. Das Vlies transportiert das Wasser aus der tieferen Drainageschicht über die Kapillaren in die Wurzelzone des Rasens, so dass das Wasser dem Rasen zur Verfügung steht. Um diese Funktion zu gewährleisten, muss das 150 mm breite Vlies vertikal in einer Tiefe von 170 mm +-20 mm verlegt werden. Bei der Verlegung darf die Bodenbedeckung nicht verringert und die Rauheit der Oberfläche nicht erhöht werden. In der vorliegenden Arbeit wird ein Gerät vorgestellt, das die Grasnarbe schneidet, eine Furche öffnet, das Vlies einarbeitet und die Furche wieder schließt. Das Gerät ist an den Traktor angebaut und besteht aus einer Höhenführung, einer Schneidscheibe, einem Kastenschar und einer Andruckrolle. Das Gerät wurde auf drei Rasenparzellen mit Tragschichtaufbau in Stuttgart getestet. Die Schneidscheibe verhinderte erfolgreich die Entstehung von Verstopfungen im Arbeitsbereich. Ein Messwagen, der mit einem Ultraschallsensor, einem Laserentfernungsmesser und einem Tastrad ausgestattet ist, ermittelte die Oberflächenrauhigkeit vor und nach der Einarbeitung des Vlieses. Die Ergebnisse zeigten eine deutliche Zunahme der Rauheit. Um die negative Veränderung der Bodenoberfläche zu reduzieren wäre es möglich die Ballastierung des Arbeitsgerätes zu erhöhen. Dabei müssen jedoch schädliche Bodenverdichtungen vermieden werden. Die gleichmäßige Tiefe des Vlieses wurde mit einem Tachymeter bestimmt und zeigte eine Abweichung von der Solltiefe von weniger als 20 mm. Die Bodenbedeckung wurde vor und nach dem Einbau des Vlieses gemessen. Die Beschädigung der Grasnarbe betrug weniger als 15 % der Bodendecke, was den Anforderungen an die Bespielbarkeit entspricht. Die Rückverfestigung wurde mit einem Penetrologger bestimmt und im Profil ausgewertet. Die als Eindringwiderstand gemessene Rückverfestigung des Bodens entsprach dem Status quo, mit Ausnahme des Bereichs direkt neben dem Vliese, wo die Rückverfestigung nicht ausreicht. Die Furchen des entwickelten Gerätes könnten durch den Einsatz von zwei V-förmig angebrachten Andruckrollen besser rückverfestigt werden. Es muss jedoch sichergestellt werden, dass die beiden Andruckrollen keine Dammbildung verursachen, wie es bei Sämaschinen der Fall ist. Insgesamt kann die Leistung des Geräts als positiv angesehen werden, aber es sind noch Verbesserungen erforderlich, um die Rückverfestigung zu verbessern. Diese Verbesserungen können in zukünftigen Untersuchungen überprüft werden. Gleichzeitig muss die Wirksamkeit des Vlieses bewertet werden. Dies war nicht Bestandteil der vorliegenden Arbeit. Vorversuche haben gezeigt, dass die Kapillarwirkung ausreicht, um Wasser aus der Drainageschicht in die Wurzelzone zu transportieren.

Curriculum Vitae

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