Journal of Water Resource and Protection, 2017, 9, 799-810
http://www.scirp.org/journal/jwarp
ISSN Online: 1945-3108
ISSN Print: 1945-3094

Effects of Turfgrass Thatch on Water Infiltration, Surface Runoff, and Evaporation

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How to cite this paper: Liang, X., Su, D.R., Wang, Z. and Qiao, X. (2017) Effects of Turfgrass Thatch on Water Infiltration, Surface Runoff, and Evaporation. *Journal of Water Resource and Protection*, **9**, 799-810.
https://doi.org/10.4236/jwarp.2017.97053

Received: May 17, 2017
Accepted: June 13, 2017
Published: June 19, 2017

Abstract

The development of a (layer of) thatch in turfgrass causes important changes to near-surface eco-hydrological processes. In this study, we investigated the effects of turfgrass thatch, specifically Kentucky bluegrass (*Poa pratensis* L.) and red fescue (*Festuca rubra* L.) on water infiltration, surface runoff, and soil moisture evaporation. The thatches were collected from the field for controlled experiments using packed soil columns under various rainfall conditions. Results indicated that the presence of thatch delayed the onset of infiltration compared with situations without a thatch at the soil surface. Infiltration was delayed for a longer period in thicker red fescue thatch than thinner Kentucky bluegrass thatch. The presence of a thatch reduced runoff by holding more water locally during the rainfall period and allowing a longer period of time for infiltration. Additionally, evaporative water loss was reduced with the presence of thatch than that of bare soil. Our results highlight that the presence of thatch changes the near-surface hydrological processes, which may help improve turf management practices in terms of thatch control and irrigation scheduling.

Keywords

Turfgrass Thatch, Infiltration, Runoff, Evaporative Water Loss

1. Introduction

Turfgrass thatch is a tightly intermingled layer of dead leaves, stems, and roots that develop between the zone of green vegetation and soil surface [1]. Usually, turfgrass thatch is more porous than non-organic soils with lower bulk density and higher porosity [2]. However, due to the deposition of a large amount of dust, thatch can also become dense and compact. By accumulating plant tissues over time and forming a porous medium at the soil surface, thatch can hold a large amount of rainfall or irrigation water that will eventually seep into the soil or evaporate into the air [3] [4] [5]. Thus, the development of thatch alters the hydrological processes at the soil surface by changing the partitioning of rainfall into infiltration, runoff, and evaporation.

In turf management practices, thatch is usually removed to maintain turf quality [2]. The effects of turfgrass thatch on soil hydrological processes are rarely reported in the literature. Turfgrass thatch is assumed to be comparable to vegetation litters at forest floors and in grasslands due to their similar biological characteristics. Vegetation litters can intercept rainfall and maintain the water input up to their maximum water holding capacity [6] [7] [8]. For instance, the rainfall interception by grassland litters was 5.3 to 6.6 mm annually in Northeastern China [9]. The maximum water holding capacity by litters was 1.7 to 3.5 times of their dry weight, and the saturated water content ranged from 12% to 60% on a volumetric basis [10] [11] [12] [13]. The water holding capacity of litters is a function of litter mass properties and rainfall conditions [6] [14] [15].

A soil surface cover (*i.e.*, vegetation litters, thatch, and mulch) is able to temporarily hold rainfall or irrigation water until it reaches its maximum capacity which is higher than that of soils [2] [6]. The presence of a soil surface cover thus delays the initiation of infiltration and increases infiltration depths by allowing for a longer infiltrating time [5] [16]. The improvement in infiltration could be attributed to the reduced impact of raindrops on the surface soil, improve soil structure by increased porosity and organic matter content, and a relatively rougher microtopography [8] [17] [18]. A soil surface cover of plant tissues also impedes overland flow and reduces the occurrence and quantities of surface runoff [14] [17] [19]. For instance, surface runoff quantities in the forest with higher litter mass and coverage were 50% - 75% lower than the ones with lower litter mass and coverage [6]. In another study, treatments with lower quantities of litters or dead herbage were consistently associated with earlier and more intensive runoff occurrence [14]. As a soil surface cover similar to vegetation litters and mulch, thatch is likely able to improve infiltration and mitigate surface runoff.

Presumably, the presence of a thatch layer has the potential to reduce soil moisture evaporation, which is similar to the effect of mulching. For instance, the cumulative evaporation of soil moisture was lower in mulched soils than bare soils, and the reduction was related to mulch coverage and mass [16] [20]. The presence of soil surface cover controls soil evaporation via two basic mechanisms: reducing radiation flux into and from the soil surface and cutting off the upward capillary flux at the soil-thatch interface [17] [21].

Soil surface cover (*i.e.*, vegetation litter, thatch, and mulch) generally helps increase water holding capacity of the surface soil, enhance infiltration, and reduce runoff and evaporation [3] [7] [20]. However, thatch is usually considered detrimental to the health of turfgrass and is removed to reduce the chances of diseases and insects. Thus, its impact on hydrological processes at the soil surface has not been well documented. The objectives of the current study were to determine the effects of thatch on infiltration, surface runoff, and evaporative water loss in a series of laboratory experiments.

2. Materials and Methods

2.1. Turfgrasses, Thatches, and Soil

Intact thatch patches were collected from turfgrass plots of Kentucky bluegrass (*Poa pratensis* L.) and red fescue (*Festuca rubra* L.), which established from sods approximately three years before the current experiment. The turfgrass plots were located at the Agricultural Experimental Station of Northwest A & F University in Yangling, Shaanxi, China (34.30˚N, 108.08˚E). The thatch thickness was 1 and 3 cm in the plots of Kentucky bluegrass and red fescue, respectively. Pieces of thatches of Kentucky bluegrass and red fescue were cut into the size of 10 × 10 cm for measuring thatch properties and effects on hydrological processes.

Soil was collected from a depth of 0 - 30 cm below the turfgrass and classified as loam consisting of 50% sand, 35% silt, and 15% clay. To measure soil saturated water content, soil was packed into rings of 5-cm height and diameter to its natural bulk density (Table 1). The rings were soaked in distilled water for 12 h to achieve matrix saturation and then weighed to calculate soil water content at saturation on a volume basis.

The soil was air dried at room temperature (approximately 20˚C) for 72 h, sieved through a 2-mm meshed sieve, and packed into Plexiglas columns to its natural bulk density. The dimensions of Plexiglas columns were 10 × 10 cm in cross-sectional area and 60 cm in height, without a bottom lid to allow free drainage of water and air.

2.2. Measurement of Thatch Properties

Thatch patches were washed to remove soil and green vegetation attached to them in order to exclude their effects on the measurements of thatch properties. Cleaned thatches were oven dried at 70˚C for 48 h to determine the dry mass of the thatch. They were then soaked in distilled water for 12 h to achieve tissue and matrix saturation [3]. The sponge-like saturated thatches were taken out of the water and held in the air to allow the gravity water to drain out completely [15]. The measurements were repeated four times in each turfgrass species. The tissue-saturated water content and bulk density of the thatch were calculated using:

$$\theta_{ts} = \frac{(M_s - M_d)/\rho}{V_T} \tag{1}$$

$$\rho_b = \frac{M_d}{V_T} \tag{2}$$

where θ_{ts} is the tissue-saturated water content (cm^3/cm^3); M_s is the tissue-saturated mass of the thatch (g); M_d is the dry mass of the thatch (g); ρ is the density of water (1.0 g/cm^3); and V_T is the bulk volume of the thatch (cm^3) (*i.e.*, 100 cm^3 of the Kentucky bluegrass thatch and 300 cm^3 of the red fescue thatch); ρ_b is the bulk density of the thatch.

2.3. Measurement of Infiltration

The air dried soil was packed into Plexiglas columns to a 50-cm height, leaving 10-cm free space in the top part to allow water-ponding during the rainfall events. Water was sprinkled on top of the columns as simulated rainfall with application levels of 12.5, 25.0, 37.5, and 50.0 mm per 30 min. The soil surface in the columns was either bare or covered by dry thatch patches, and for each rainfall application level, there were three soil coverage treatments: bare soil, Kentucky bluegrass and red fescue thatches. The four levels of rainfall application were selected to create different infiltration scenarios in order to test the hydraulic properties of the turfgrass thatch in a broad range of situations. The propagation of the infiltration depth was recorded from the initiation of rainfall application and averaged on each side of the column. The depth of cumulative infiltration was recorded every 5 min in the first 2 h, every 30 min in the next 2 h, and every hour until there was no more increase in the depth. Since the cross-section area of the column was small, the infiltration depth observed on the side of the column was assumed to be equivalent to that in the center [22]. The experiment was replicated twice, and the average was used to obtain the relationship between cumulative infiltration depth and infiltrating time.

The Lewis-Kostiakov equation is one of the most commonly used empirical models to describe the relationship between cumulative infiltration (I, L or cm) and infiltrating time (t) (Equation (3)) [23] [24] [25]. This equation was selected in the current study because of less restriction on the mode of water application and no requirement of assumptions regarding to soil surface and profile conditions [26] [27]. Additionally, the equation applies well from early to intermediate infiltration times before approaching a constant infiltration rate [23].

$$I = kt^{\alpha} \quad (3)$$

where k and α are empirical coefficients without physical interpretation and must be evaluated from measured infiltration data [27]. In the current study, the cumulative infiltration was expressed as infiltration depth (cm), and the infiltrating time was in the unit of minutes.

2.4. Measurement of Runoff

Columns were filled with the air-dried soil to the top (with a height of 60 cm) in the treatment of bare soil. In the two treatments with thatch placed at the soil surface, soil was filled in the columns in order to level the thatch surface with the top edge of the column: Kentucky bluegrass with a height of 1 cm thatch plus 59 cm soil and red fescue with a height of 3 cm thatch plus 57 cm soil. Water was sprinkled as simulated rainfall to the soil or thatch surface at a constant rate of 25 mm/h until runoff occurred. Runoff was defined as the occurrence when water and sediments began to flow off the soil or thatch surface. The rainfall duration till the runoff occurrence (runoff initiation time) and the applied quantity of water (rainfall amount) were recorded. The infiltration depth in the soil was measured at the runoff occurrence. This runoff experiment was repeated for four times.

2.5. Measurement of Moisture Evaporation from the Soil Surface and Thatch

Soil columns were filled following the description in "Measurement of Runoff". Two levels of infiltration (12.5 and 37.5 mm) were sprinkled at the soil or thatch surface of Kentucky bluegrass and red fescue in 30 min. Covers were mounted on columns at the end of water application to prevent evaporation and were removed 12 h following the cessation of water application. Soil moisture, infiltration depth, and thatch water content were measured 12 and 24 h after the cessation of water application. Soil moisture was measured from the soil surface to a depth of 57 mm using a Hydra Probe Soil Moisture and Salinity Sensor (Stevens Water Monitoring Systems, Inc. Portland, OR). Evaporative water loss was calculated as the sum of moisture loss from the soil at 0 - 57 mm and from thatch between 12 and 24 h following the cessation of water application. Soil moisture in the infiltrated soil profile below 57 mm was assumed to be at field capacity (0.25 cm^3 cm^{-3}). The experiment was replicated twice.

2.6. Data Analysis

Data were analyzed using the glm procedure of SAS (Ver. 9.3. SAS Institute, Inc. Cary, NC). Pairwise comparisons were made using the lsmeans statement and the Tukey's honest significant difference test in the measurement of runoff and using 95% confident intervals for the other variables. Regression analysis was performed using SigmaPlot (ver. 13.0 Systat Software Inc. San Jose, CA) and SAS to obtain the relationships between infiltration depth and infiltrating time. All figures were created using SigmaPlot.

3. Results

3.1. Physical Properties of Thatches Compared with Soil

Red fescue thatch possessed greater dry and tissue-saturated mass than Kentucky bluegrass thatch, but their tissue-saturated over dry mass or water content at saturation did not differ (Table 1). Saturated water content of soil was lower than either turf thatch. Bulk densities of the two thatches (Kentucky bluegrass and red fescue) did not differ between each other, but were lower than that of the soil.

3.2. Water Infiltration

Compared with the bare soil treatment, the cumulative infiltration depth was smaller when thatches were present at the soil surface at each level of rainfall application (Figure 1). Red fescue thatch showed consistently lower cumulative infiltration than Kentucky bluegrass thatch at each level of rainfall application.

Table 1. Means (n = 4) of physical properties of red fescue (RF) and Kentucky bluegrass (KB) thatches and soil.

Physical property	RF	KB	Soil
Dry mass (M_d, g/m^2)	4.30 × 103 A	1.06 × 103 B	---
Tissue-saturated mass (M_{ts}, g/m^2)	1.70 × 104 A	4.93 × 103 B	---
Tissue-saturated over dry mass (M_{ts}/M_d)	4.78	3.96	---
Dry bulk density (g/cm^3)	0.15 B	0.12 B	1.58 A
Water content at saturation (cm^3/cm^3)	0.48 A	0.41 A	0.33 B
Field capacity (cm^3/cm^3)	---	---	0.25

Different letters represent significant differences within each physical property ($P \le 0.05$).

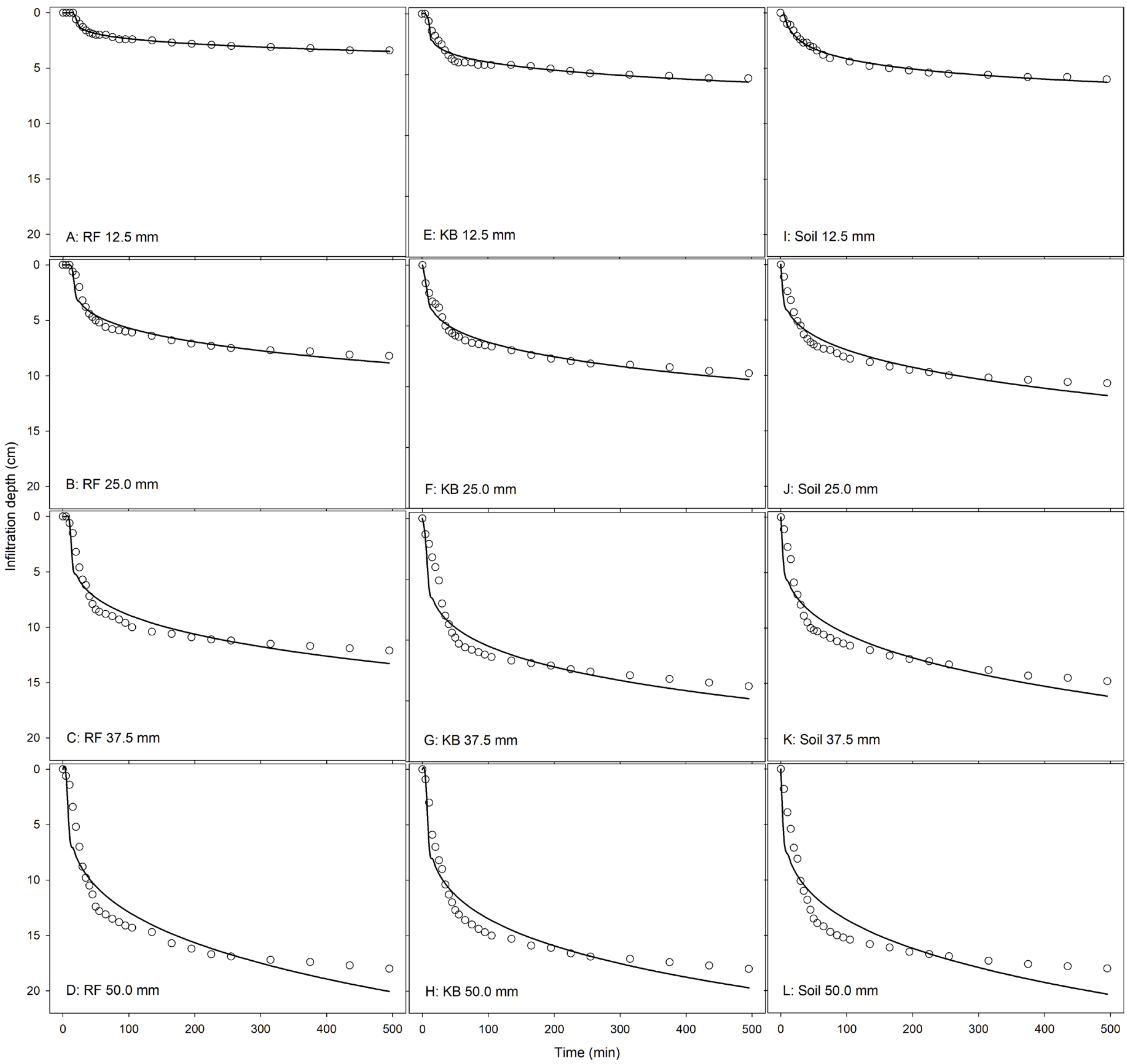

Figure 1. Relationships between infiltration depth and infiltrating time simulated by Equations ((3) and (4)) in red fescue (RF) thatch ((A)-(D)), Kentucky bluegrass (KB) thatch ((E)-(H)), and bare soil (Soil) ((I)-(L)) under rainfall application of 12.5 ((A), (E), and (I)), 25.0 ((B), (F), and (J)), 37.5 ((C), (G), and (K)), and ((D), (H), and (L)) 50.0 mm.

Table 2. Coefficients (±standard error) and performance of Equations ((3) and (4)) at four infiltration quantities (*i.e.*, 12.5, 25.0, 37.5, and 50.0 mm) in with soil coverage of red fescue (RF) and Kentucky bluegrass (KB) thatches and bare soil (Soil).

Soil surface cover	Coefficient			Performance	
	k	α	c (min)	R^2	P-Value
		12.5 mm			
RF	0.879 ± 0.0386	0.224 ± 0.00872	19.6 ± 0.135	0.998	<0.001
KB	1.58 ± 0.144	0.206 ± 0.0184	10.2 ± 0.284	0.993	<0.001
Soil	0.762 ± 0.103	0.350 ± 0.0256	----	0.935	<0.001
		25.0 mm			
RF	1.84 ± 0.204	0.254 ± 0.0218	15.0 ± 0.0462	0.997	<0.001
KB	2.12 ± 0.166	0.240 ± 0.0155	4.63 ± 0.275	0.994	<0.001
Soil	2.24 ± 0.253	0.268 ± 0.0222	----	0.914	<0.001
		37.5 mm			
RF	3.05 ± 0.362	0.238 ± 0.0236	10.2 ± 0.00804	0.993	<0.001
KB	4.02 ± 0.431	0.210 ± 0.0215	4.78 ± 0.0850	0.847	<0.001
Soil	3.10 ± 0.408	0.266 ± 0.0260	----	0.886	<0.001
		50.0 mm			
RF	3.78 ± 0.531	0.269 ± 0.0276	4.80 ± 0.0116	0.981	<0.001
KB	4.69 ± 0.496	0.232 ± 0.0211	4.80 ± 0.00565	0.872	<0.001
Soil	4.28 ± 0.605	0.251 ± 0.0280	----	0.859	<0.001

Cumulative infiltration depth and infiltrating time were well fitted by the Lewis-Kostiakov equation (Equation (3)) with no thatch at the soil surface (Table 2 and Figure 1). The presence of thatches delayed the infiltration process. Due to the delay effect, I and t could not be well fitted by the Lewis-Kostiakov equation, and a modification was made (Equation (4)). When a thatch was present at the soil surface, the section of $t \le c$ in Equation (4) could precisely describe the infiltration delay (Table 2 and Figure 1).

$$
\begin{aligned}
&I = 0 \quad \text{when } t \le c \\
&I = k\left(t-c\right)^{\alpha} \quad \text{when } t > c
\end{aligned}
\tag{4}
$$

where I, t, k, and α are the same as Equation (3). Coefficient c (min) indicates infiltration delay due to the presence of thatch at the soil surface.

Coefficient c (or infiltration delay) was greater in red fescue thatch than Kentucky bluegrass thatch at rainfall application levels of 12.5, 25.0, and 37.5 mm by comparing 95% confidence intervals of c in different thatches (Table 2). It could be explained by the greater tissue-saturated mass of red fescue thatch, which could hold a substantial amount of water until the infiltration began (Table 1). But at the highest rainfall application level (*i.e.*, 50.0 mm), coefficient c was not different between the two thatches (Table 2). At each level of rainfall application, coefficient k and α were not different among Kentucky bluegrass and red fescue thatches and soil by comparing their 95% confident intervals, indicating the infiltration process was not altered by the presence of thatch once infiltration initiated.

3.3. Surface Runoff

In the treatments with Kentucky bluegrass or red fescue thatch placed at the soil surface, rainfall amount, runoff initiation time, and infiltration depth were greater than the treatment of bare soil (Table 3). The presence of thatches thus delayed the runoff occurrence. Red fescue thatch also exhibited greater rainfall amount, runoff initiation time, and infiltration depth than Kentucky bluegrass thatch (Table 3), and the differences could result from the greater dry and tissue-saturated mass of red fescue thatch (Table 1).

3.4. Evaporative Water Loss from the Surface Soil and Thatch

At the infiltration amounts of 12.5 and 37.5 mm, evaporative water loss was lower when red fescue thatch was presented compared with Kentucky bluegrass thatch and bare soil (Figure 2). Evaporative water loss was the highest in the

Table 3. Means (n = 4) of rainfall amount, rainfall application time till the onset of runoff (runoff initiation time), and the corresponding soil infiltration depth with soil surface coverage of red fescue (RF) and Kentucky bluegrass (KB) thatches and bare soil (Soil).

Soil surface cover	Rainfall amount (mm)	Runoff initiation time (min)	Infiltration depth (cm)
RF	44.1 A	106 A	4.36 A
KB	21.2 B	51 B	2.95 B
Soil	5.66 C	14 C	1.08 C
P-value	<0.001	<0.001	<0.001

Different letters represent significant differences within each column ($P \leq 0.05$).

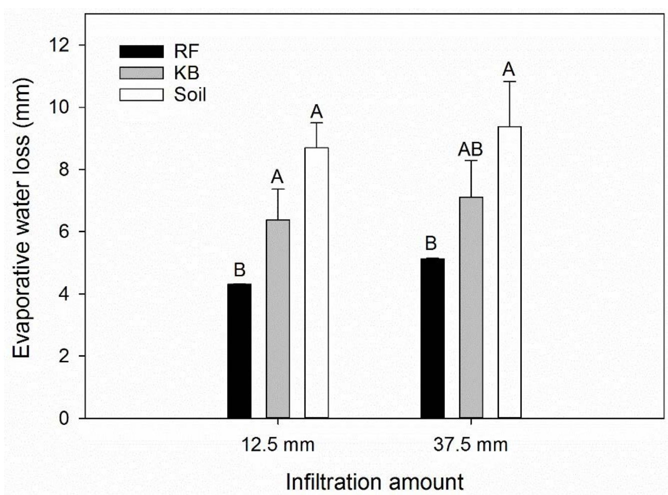

Figure 2. Evaporative water loss under red fescue (RF) and Kentucky bluegrass (KB) thatches and bare soil (Soil) with total infiltration quantities of 12.5 and 37.5 mm. Different letters represent significant differences ($P < 0.05$) by comparing 95% confidence intervals, and multiple comparisons were within each infiltration amount.

bare soil among the three treatments of soil surface cover at both infiltration amounts.

4. Discussion

Kentucky bluegrass and red fescue are turfgrass species that can easily develop thatch [28] [29]. The formation of thatch can be attributed to their extensive production of rhizomes [28] [29]. Red fescue has a creeping growing habit, contributing to the formation of denser and thicker thatch compared with Kentucky bluegrass [28] [29]. For instance, the thatch thickness could reach 6.4 cm on an eight-year-old red fescue turf [1], while that of an eight-year-old Kentucky bluegrass was 2.1 cm [4]. Thus, the characteristics of turfgrass determine the formation, mass accumulation, and thickness of its thatch, which eventually determines the water holding capacity of the thatch. It has been reported that creeping bentgrass (*Agrostis stolonifera* L.) thatch, 13 to 19 mm thick, could retain water more than 50% the thatch thickness [3] [30]. The high water holding capacity of thatch derives from their high porosity [3] [5].

After the onset of rainfall or irrigation, some water is intercepted and held in the pore space of thatch and thus delays the initiation of water entering the soil [2] [3] [5] [17]. For instance, Taylor and Blake (1982) [5] showed that for 20 mm of water to infiltrate into a sandy soil, it took 0.36 min; whereas it took 6.34 min for the same amount of water to infiltrate into the same soil with Kentucky bluegrass thatch at the surface. In the current study, the presence of thatch delayed the initiation of infiltration, expressed as coefficient c in Equation (4) (**Table 2** and **Figure 1**), which was consistent with decreased initial infiltration rates due to the presence of thatch in previous studies [2] [3] [5]. But the delay effect has seldom been quantified timewise or expressed using equations. Once infiltration initiated at the presence of thatch, the infiltration process was not different from bare soil, indicating by similar coefficients k and α at certain infiltration amounts (**Table 2** and **Figure 1**). It could be explained that coefficients k and α are more determined by soil properties (*i.e.*, pore size distribution and saturated hydraulic conductivity) [23].

Runoff yield decreased with the increase in litter mass at the soil surface, and the time until runoff occurred postponed with increased litter mass [31]. Increased detention of runoff has also been observed in creeping bentgrass compared with perennial ryegrass (*Lolium perenne* L.) due to higher thatch mass accumulated in creeping bentgrass [3]. Thus, differences in thatch formation and characteristics contribute to the differences in hydrological processes [3]. In the present study, the thicker red fescue thatch may hold more water and produce a more tortuous pathway for downward movement of water entering the soil; and showed a longer postpone of infiltration and runoff compared with the thinner Kentucky bluegrass thatch.

A wet thatch could maintain a high air humidity at the soil surface, which reduces the differences of air humidity between the space immediately above and below soil surface (the drive of evaporation) [32]. Evaporative loss was thus lower when a thatch was placed at the soil surface, and the effects could be enhanced with an increased amount or thickness of thatch mass (Kentucky bluegrass vs. red fescue) (**Figure 2**). Similarly, Ji and Unger (2001) [16] found that the cumulative evaporation of soil water was lower in mulched than bare soil, and the decrease in evaporation was proportional to the mulch coverage and mass on the soil surface. In another study, soil water evaporation decreased with the increase in litter thickness of a grassland [9]. Furthermore, the presence of a thatch at the soil surface creates a capillary discontinuity at the thatch-soil interface and impedes capillary rise to thatch, which would be lost via evaporation [2]. Thus, the presence of thatch at the soil surface reduces evaporative water loss, and the effect was reinforced with the increase in thatch thickness and mass accumulation.

5. Conclusion

Thatch provides a barrier before irrigation and rainfall reach the soil and holds a substantial amount of water. The effects of thatch on infiltration should be considered in irrigation scheduling since lower irrigation quantity than the water holding capacity of thatch will not reach the soil [2]. The increased tortuousness/roughness at the soil surface by thatch delays runoff occurrence and allows more water to infiltrate into the soil. It can also reduce pollutions to nearby watersheds caused by nutrients and pesticides in the runoff. Moreover, the presence of thatch changes the microenvironment at the soil surface and decreases surface soil moisture evaporation. The effects are similar to mulching in soil moisture conservation [16] [20]. For golf courses and lawns of potential concerns in water management, maintaining thatch to a certain extent or selecting species/genotypes of high thatch productivities might be considered.

Acknowledgements

This study was funded by the Chinese National Natural Science Foundations (50679002), Chinese Education Commission's Project 111 (B08039) and the National Technology Supporting Program (2006BAD16B09). We acknowledge the help from Qiao Liu in the study.

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