Effects of land use on soil saturated hydraulic conductivity of Horqin Sand Land

S.X. YAO[1,2], C.C. ZHAO[1,2], X.M. ZHAO[3], S.Y. WANG[1], Y.J. LI[1], L.N. TIAN[1]

1. Lanzhou City University, Lanzhou 730070, China;

2.Cold and Arid Regions of Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China;

3. Department of Basic Courses, Lanzhou Institute of Technology, Lanzhou 730000, China

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ABSTRACT: In order to analyze the influence of land use on soil saturated hydraulic conductivity (Kfs), three typical sandy lands of Horqin Sand Land were chosen, including pine woodland, poplar woodland and farmland, and three fields for each type to identified for Kfs measurement. The Kfs of five soil depths (0~20cm, 20~40 cm, 40~60cm, 60~80cm and 80~100cm) at each field was measured in situ by Guelph Permeameter. The relationship of Kfs with sand types, soil depths, and soil physiochemical properties were analyzed. The results showed that (1) The averaged Kfs was decreased in the order: pine woodland > poplar woodland > farmland, with averaged value was 3.99，2.60 and 0.93 mm/min, that was, Kfs of Horqin Sand Land was largely influenced by land use. (2) The trend in Kfs with increasing soil depth was not consistent among the type of sand land, e.g., the changes of Kfs along with soil depth in pine woodland was fitted by parabola model, but there was no law for poplar woodland and farmland. (3) The relationships of Kfs and soil physiochemical property revealed that soil organic matter content and mechanical components were the key factors affecting Kfs of Horqin Sand Land, next was soil bulk density, and Kfs increased with increasing coarse sand fraction (2~0.1 mm) and bulk density, but Kfs decreased with increasing soil clay and silt content proportion (that was 0.1~0.05mm and <0.05mm, respectively), and organic matter content.

INTRODUCTION

Soil saturated hydraulic conductivity (Kfs) refers to the amount of water passing through unit area in unit time under unit water potential gradient when the soil is water-saturated. It can be used to reflect the infiltration and seepage properties of soil, and serve as an important parameter for studying the moisture and solute transport, speculating the soil non-saturated hydraulic conductivity, calculating the soil profile water flux, and designing irrigation drainage system projects (Fares et al. 2000). In the meanwhile, the Kfs is an important parameter in the study of water balance, which affects the distribution relationship among ground water infiltration, runoff and evapotranspiration (Zheng et al. 2004). It is influenced by many factors, such as soil moisture characteristics, soil texture, structure, organic matter content and land use pattern (Hu et al. 2005). Therefore, the Kfs has a high degree of spatial variability, and such spatial variability is used as an important factor in the water distribution relationship of the ecological system (Niu et al. 1999). The development and utilization of the sandy land as an important land resource has attracted high attention. Water is a dominant factor in sandy habitats, and the study of its parameters is conducive for understanding the dynamic characteristics of soil moisture, thereby laying a foundation for research on the water consumption patterns of plants under natural conditions and water cycle characteristics (Su. 2000).

At present, studies on Kfs mostly focus on the determination method (Amoozegar. 1989), model prediction (Tietje & Hennings, 1996), spatial heterogeneity of top Kfs (Zhao et al. 2009) and other aspects. However, there are not many comparisons of and studies on sandy Kfs under different land use patterns (Liang et al. 2009; Price et al. 2010). Among them, there are many methods available for the determination of Kfs, such as double ring method, parameter method and soil column method. Guelph infiltrometer (Guelph Permeator, 2008KI, Santa Barbara, CA93105, U. S. A.) is a portable infiltration device for in situ determination of Kfs by using the principle of steady

water-head infiltration (Yao et al. 2013(a)). In view of this, with Horqin Sandy Land, one of China's largest four sandy lands, as the study area and relying on Naiman Station for Desertification Experiment and Research of the Chinese Ecosystem Research Network, this study selected sandy lands of three land use patterns (pine woodland, poplar woodland and farmland) as the objects of study, and applied Guelph infiltrometer to study the change patterns of *Kfs* at different soil layers (every 20cm was a new soil layer, and the lower limits of soil layer were respectively 20 cm, 40 cm, 60 cm, 80 cm and 100 cm) of these three types of sandy land and their relationship with the land use type so as to provide certain guidance and a theoretical basis for research on vegetation construction, ecological restoration and soil and water conservation in this region.

MATERIAL AND METHODS

Study site description
The study sites located at Naiman County in southwestern of Horqin Sand Land, North China. At the region, the 40–yr annual mean precipitation was 360 mm, 75% of which is received from June to September, and the annual mean potential evaporation is 1991 mm. The 40–yr annual mean temperature is around 6.4˚C, with the minimum monthly mean temperature of –13.1˚C in January and the maximum 23.7 ˚C in July. The annual mean wind velocity is in the range of 3.2~4.1 m s^{-1}. The soil, with loose sand and low content of organic matter, is vulnerable to wind erosion and aeolian soil which degraded from sandy chestnut soil (Yao et al. 2013(b)).

Study method

Site choosing
Three typical sites were selected for measurement of *Kfs* from Naiman County in this study, including pine woodland, hereinafter, for PNW, poplar woodland for PW and farmland for FL. There were three fields with similar settings each other as three replications for each site. On each field, 15 sample points spaced 5 meters apart were selected, a total of 135 sample points.

Soil sampling and soil properties determining
A soil profile with 1m depth near to the *Kfs* measuring points (that was, sample point) was dug for each field. Three undisturbed soil samples for each layer were taken on the profile at interval with 20 cm using a cylindrical metal core with a height of 5 cm and a volume of 100 cm^3. The soil bulk density was first measured using volume-mass relationship and then the same soil sample was used to determine other basic soil properties. The soil organic matter content was determined using the $K_2Cr_2O_7$–H_2SO_4 wet oxidation method (Institute of Soil Sciences, 1978). The soil particle size distribution was determined by dry sieving method. Each soil properties were all the average of three replicates for each field.

Measured of Kfs
Kfs was calculated as follows function through inputting the parameter value of R_1 and R_2 which were determined in situ by Guelph Prememeater under constant water head at 5 cm and 10 cm, respectively. We measure 5 layers from surface to bottom at a soil profile with an interval 20 cm in a measuring point.

$Kfs = 35.22 \times (0.0041 \times R_2 - 0.0054 \times R_1).$ (1)

Data analysis
Microsoft Excel was employed for test data processing; 3S method in DPS software was used to exclude *Kfs* outliers of different depths of the three types of sandy land (significance level p=0.05), and Shapiro-Wilk test method in the software was used for normality test of *Kfs* values; SPSS15.0 software was employed for significance test of the differences in *Kfs* of different depths among various types of sandy lands (significant level *p*=0.05); correlation analysis in SPSS15.0 software

was used to analyze the correlation of *Kfs* and bulk density, organic matter, mechanical components and other physical and chemical factors of the three types of sandy land.

RESULTS

Changes of some soil physical and chemical properties

The results of analysis on soil physical and chemical properties of the three types of sandy land are shown in Table 1. It could be seen that (1) from the point of view of the average value, there was not much difference in the bulk density of the three types of sandy land; the bulk density of pine woodland and poplar woodland was higher (1.54 g/cm^3), while that of farmland was lower (1.44 g/cm^3). In light of different depths, the bulk density was higher at the depth of 40~60 cm of pine woodland and poplar woodland and 0~20 cm of farmland; (2) organic matter content in farmland was the highest, and the average value was 44 g/kg, because fertilization greatly increased the organic matter in farmland; the content in poplar woodland was lower, and the average value was 20 g/kg; the content in pine woodland was the lowest, and the average value was 11 g/kg. According to different soil thickness, except for poplar woodland, the organic matter content at the depth of 0-20 cm of the other two types of sandy land was higher than other depths, mainly because wind erosion and falling objects increased the organic matter content in topsoil; (3) analysis on the variation of the mechanical composition of the three types of sandy soil showed that the variation pattern of coarse sand content (2~0.1 mm) and fine sand content (1~0.05 mm) was "pine woodland > poplar woodland > farmland", and the variation pattern of silt clay content (<0.05 mm) was "pine woodland < poplar woodland < farmland". With the increase in the thickness of soil layer, sand (coarse sand and fine sand) content in the three types of sandy land showed a gradually decreasing trend, while silt sand content basically showed a gradually increasing trend.

Overall, physical and chemical properties of farmland were significantly different from those of pine woodland and poplar woodland, while the difference between pine woodland and poplar woodland was relatively insignificant.

Table 1. Soil physical and chemical properties at three sites.

Site	Soil layer (cm)	Bulk density (g cm^{-3})	Total porosity (%)	Organic matter content (g/kg)	Soil particle size distribution (%) 2~0.1 mm	0.1~0.05 mm	<0.05 mm
PNW	0–20	1.56	41.12	16.5	97.55	1.25	0.55
	20–40	1.52	42.56	10.0	97.08	1.57	0.68
	40–60	1.56	41.29	8.8	97.02	1.68	0.68
	60–80	1.55	41.60	8.1	97.08	1.35	0.83
	80–100	1.51	43.12	11.5	94.52	2.28	2.28
	Mean	1.54	41.94	11.0	96.65	1.63	1.00
PW	0–20	1.56	41.18	19.5	87.17	9.20	2.95
	20–40	1.57	40.92	16.5	84.17	12.08	3.07
	40–60	1.59	40.06	18.8	82.15	12.58	4.40
	60–80	1.53	42.16	23.0	70.30	20.26	8.55
	80–100	1.45	45.27	24.1	61.59	25.68	11.78
	Mean	1.54	41.92	20.4	77.08	15.96	6.15
FL	0–20	1.47	44.45	51.2	55.93	25.64	17.36
	20–40	1.42	46.50	42.8	54.72	22.70	20.88
	40–60	1.45	45.44	34.3	45.05	31.04	22.54
	60–80	1.38	47.94	39.3	43.52	32.04	23.19
	80–100	1.46	45.06	49.7	42.27	29.23	26.95
	Mean	1.44	45.88	43.5	48.30	28.13	22.18

Changes of Kfs with the type of sandy land

In order to reduce the influence of outliers on the analysis results, 3S method in DPS software (significance level p=0.05) was employed to pick out and exclude *Kfs* outliers of different depths of various types of sandy land, in which pine woodland and farmland each had two outliers, and poplar woodland had one outlier. Then the average value of *Kfs* of different depths of the three types of sandy land was selected, and Shapiro-Wilk test method in DPS software was used for normality test of *Kfs* of the three types of sandy land. The results showed that *Kfs* of different depths of the three types of sandy land obeyed lognormal normal distribution, consistent with relevant research results (Mohanty et al. 1994).

Analysis on the statistical characteristics of *Kfs* at different soil layers of the three types of sandy land showed (Table 2) that the mean value of *Kfs* at five soil layers of pine woodland was the highest with an average of 3.99 mm/min, followed by that of poplar woodland with an average of 2.60 mm/min, and that of farmland was the lowest with an average of 0.93 mm/min. Mean value of the standard error of *Kfs* at different soil layers of the three types of sandy land was the highest in pine woodland at 0.45, lower in poplar woodland at 0.32, and the lowest in farmland at 0.21. In other words, the greater *Kfs* of the three types of sandy land, the greater their standard error. The coefficients of variation of *Kfs* of the three types of sandy land were all lower than 1, which belonged to medium variation. Mean value of the skewness at different soil layers of the three types of sandy land was higher in pine woodland and farmland at 0.84 and 0.85, respectively, and that of poplar woodland was lower at 0.73; Kurtosis mean values of *Kfs* of pine woodland and poplar woodland were both positive, but the former was higher than the latter, while the Kurtosis mean value of farmland was negative, mainly because the soil physical and chemical properties of farmland (Table 1) were significantly different from those of the other two types of sandy land.

Table 2. Statistical characteristic of *Kfs* at three sites.

Site	Soil layers /cm	Min.	Max.	Mean	Se	CV	Skew-ness	Kur-tosis
PNW	0~20	0.02	10.25	4.36 ac	0.38	0.58	0.33	-0.39
	20~40	0.03	9.25	3.18 bc	0.43	0.80	0.76	-0.29
	40~60	0.03	9.54	2.32 b	0.33	0.87	1.45	3.15
	60~80	0.10	13.13	4.76 a	0.56	0.71	0.70	-0.21
	80~100	0.07	14.88	5.33 a	0.54	0.64	0.97	0.91
	Mean	0.05	11.41	3.99 A	0.45	0.72	0.84	0.63
PW	0~20	0.01	4.82	2.20 bc	0.19	0.55	0.19	-0.21
	20~40	0.13	8.05	3.06 ac	0.33	0.67	0.47	-0.50
	40~60	0.01	5.43	1.96 b	0.22	0.66	0.72	0.08
	60~80	0.08	8.96	2.49 ab	0.42	0.99	1.36	1.09
	80~100	0.13	9.67	3.30 a	0.45	0.81	0.89	0.16
	Mean	0.07	7.39	2.60 B	0.32	0.74	0.73	0.12
FL	0~20	0.03	1.82	0.78 b	0.12	0.70	0.46	-1.07
	20~40	0.04	2.73	0.70 b	0.18	1.11	1.50	1.76
	40~60	0.08	1.82	0.63 b	0.13	0.91	0.75	-0.77
	60~80	0.03	3.49	1.42 a	0.25	0.79	0.58	-0.98
	80~100	0.01	3.87	1.15 ab	0.36	1.12	0.95	-0.26
	Mean	0.04	2.74	0.93 C	0.21	0.92	0.85	-0.26

Note: The different capital letter is meaning statistically significant differences between sites (p<0.05). The different little letter is meaning statistically significant differences between layers at a site.

Kfs with soil depths

Table 2 also shows *Kfs* variation with the type of sandy land and the depth of soil layer and the difference significance test results. It could be seen that the difference in *Kfs* among different sandy lands was significant (p<0.05), suggesting that different land use types had a significant impact on *Kfs*. (1) It could be seen from *Kfs* variation of each type of sandy land with the depth of soil layer that *Kfs* of pine woodland decreased first and then increased with increasing depth, showing a V type trend; the minimum and maximum values were obtained at the depth of 40~60 cm and 80~100 cm, respectively. *Kfs* of poplar woodland increased first, then decreased and increased again with increasing depth, and the minimum and maximum values were obtained at the depth of 40~60 cm and 80~100 cm, respectively. With increasing depth, *Kfs* of farmland decreased first, then increased and decreased again, just the opposite of that of poplar woodland, and the minimum and maximum values were obtained at the depth of 40~60 cm and 60~80 cm, respectively.　　Overall, *Kfs* at the depth of 40~60 cm of the three types of sandy sand was basically lower than that in other depths, and this layer became an aquitard. (2) Analysis on the difference in *Kfs* of different depths of each type of sandy land showed that except *Kfs* at the depth of 20~40 cm, *Kfs* of pine woodland at the depth of 40~60 cm was significantly different from the other four soil layers; there were considerable differences between 20~40 cm and 60~80 cm & 80~100 cm, but there were no significant differences among 0~20 cm, 60~80 cm and 80~100 cm. *Kfs* of poplar woodland at the depth of 40-60 cm was significantly different from 20~40 cm and 80~100 cm; there were high differences between 80~100 cm and 0~20 cm & 40~60 cm, while there were no large differences among the remaining soil layers. *Kfs* of farmland at the depth of 60~80 cm was significantly different from 0~20 cm, 20~40 cm and 40~60 cm, while differences among the remaining soil layers were not significant.

The changes of *Kfs* with different depths in PNW can be fitted by parabola model. The equations was

$$Kfs = 0.4851x^2 - 2.5573x + 6.3258, \ R^2 = 0.7591. (2)$$

where *x* present soil depth (20, 40, 60, 80, 100 cm).

But the changes of *Kfs* with different soil layers for PW and FL were complex and may not be fitted by any model.

Generally, the changes of *Kfs* with soil depth were different of each other for different sandy land.

Relationship of Kfs with soil physical and chemical properties

Existing studie (Shan et al. 1998) have shown that *Kfs* has a good correlation with soil bulk density, organic matter content and structure. It was found through analysis on the correlation of *Kfs* and soil physical and chemical properties of the three types of sandy land (Table 3) that *Kfs* of pine woodland, poplar woodland and farmland was significantly positively correlated with soil bulk density (*p*<0.05), and extremely significantly positively correlated with coarse sand component (2~0.1mm), while extremely significantly negatively correlated with organic matter content, fine sand component (0.1~0.05mm) and silt clay component (<0.05mm). That is to say, *Kfs* of pine woodland, poplar woodland and farmland in Horqin Sandy Land is significantly affected by the organic matter content and soil mechanical composition, and then by bulk density. Specifically, the higher coarse sand component and bulk density of the soil, the greater *Kfs*; the higher fine sand and silt clay components and organic matter content, the smaller *Kfs*, which is consistent with the existing research results (Yao et al. 2013(b)).

Table 3. Correlation of *Kfs* and soil physical and chemical properties.

Soil physical and chemical properties	Bulk density (g/cm^3)	Organic matter content (g/kg)	Soil particle size distribution (%)		
			2~0.1 mm	0.1~0.05 mm	<0.05 mm
Pearson correlation coefficient	0.356*	-0.655**	0.677**	-0.623**	-0.641**
Significance level	0.017	0.000	0.000	0.000	0.000

Note: * p<0.05; ** p<0.01.

CONCLUSIONS

Kfs of pine woodland, poplar woodland and farmland in Horqin Sandy Land differ significantly (*p*<0.05), and the average values at different soil layers are 3.99 mm/min, 2.60 mm/min and 0.93 mm/min;

The variation pattern of *Kfs* of the three types of sandy land varies—the variation of *Kfs* of pine woodland constitutes a parabola with changes in depth, while there is no regular pattern for the variation of *Kfs* of poplar woodland and farmland with changes in depth; the *Kfs* of the three types of sandy land at the depth of 40~60 cm is basically lower than other depths, this layer becomes an aquitard, and there are significant differences among partial soil layers;

Kfs of the three types of sandy land is significantly affected by organic matter content and soil mechanical composition, followed by bulk density. Besides, *Kfs* increases with the increase in coarse sand component and bulk density, while decreases with the increase of soil fine sand and silt clay component and organic matter content.

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