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Effects of Urbanization, Soil Property and Vegetation Configuration on Soil Infiltration of Urban Forest in Changchun, Northeast China

WANG Peijiang[1,2], ZHENG Haifeng[1], REN Zhibin[1], ZHANG Dan[1], ZHAI Chang[1,2], MAO Zhixia[1,2], TANG Ze[1,2], HE Xingyuan[1,2]

(1. *Key Laboratory of Wetland Ecology and Environment*, *Northeast Institute of Geography and Agroecology*, *Chinese Academy of Sciences*, *Changchun* 130102, *China*, 2. *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*)

Abstract: Urban forest soil infiltration, affected by various factors, is closely related with surface runoff. This paper studied the effect of urban forest types, vegetation configuration and soil properties on soil infiltration. In our study, 191 typical plots were sampled in Changchun City, China to investigate the soil infiltration characteristics of urban forest and its influencing factors. Our results showed that the steady infiltration rates of urban forest soil were highly variable. High variations in the final infiltration rates were observed for different vegetation patterns and compaction degrees. Trees with shrubs and grasses had the highest infiltration rate and trees with bare land had the lowest infiltration rate. In addition, our results showed that the soil infiltration rate decreased with an increase in the bulk density and with a reduction in the soil organic matter content and non-capillary porosity. The soil infiltration rate also had significantly positive relationships with the total porosity and saturated soil water content. Urban soil compaction contributed to low soil infiltration rates. To increase the infiltration rate and water storage volume of urban forest soil, proper techniques to minimize and mitigate soil compaction should be used. These findings can provide useful information for urban planners about how to maximize the water volume of urban forest soil and decrease urban instantaneous flooding.

Keywords: soil infiltration ; urbanization gradients; urban forest; plant communities; soil property

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1 Introduction

With rapid urbanization, natural vegetated soils are replaced with impervious surfaces. This land conversion could exert profound influences on hydrological processes such as inhibiting rainwater infiltration and increasing surface runoff and peak discharge rates (Hood et al., 2007; Asadian and Weiler, 2009; Endreny and Collins, 2009; Jia et al., 2015; Zhang Biao et al., 2015a). Excessive runoff accompanied by low urban forest coverage could frequently cause flooding in the urban areas and pose threats to life and property (Pataki et al., 2011; Yao et al., 2015). The increase in flood risk due to short- term heavy rains has been a major concern in many cities (United Nations, 2012). Nearly all cities have set up mitigation strategies to improve the design standards of urban drainage pipe networks. However, such strategies are costly and in-

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Corresponding author: HE Xingyuan. E-mail: hexingyuan196209@163.com

crease the pressure on sewage treatment plants. Therefore, effective and low-cost measures to solve waterlogging in cities need to be explored.

The effects of vegetation on surface water runoff have been extensively studied (Sanders, 1986; Joffre and Rambal, 1993; Ellis et al., 2006). Much research has focused on natural vegetation of the watershed in rural areas (Bu et al., 2010; Armson et al., 2013; Wang et al., 2013). There have been fewer studies about runoff mitigation of urban vegetation, especially for urban forests. Urban forests, mainly consisting of trees, shrubs and lawns, positively influence urban hydrology through soil water storage and enhanced infiltration into the root and soil zones, as well as interception by the canopy and plant stems (Gill et al., 2007; Bartens et al., 2008; Zhang et al., 2012). Urban forest soil infiltration was closely related with rainfall and irrigation water penetrating soils and then migrating and being stored in the soil (Kang et al., 2008; Yang and Zhang, 2008; Cheng et al., 2009; Saito et al., 2016). It has significant influence on surface runoff and water management (Alaoui and Goetz, 2008; Cheng et al., 2017; Zhang et al., 2017). Although many studies on urban forest soils have been conducted, most of them have focused only on soil fertility (Shan et al., 2009; Li et al., 2015), heavy metal pollutants (Pan et al., 2008; Fang et al., 2012) and soil microorganisms (Zhao and Guo, 2010; Chen et al., 2012). Most previous studies in urban areas primarily used the results from rural areas to generate the runoff reduction values (Yao et al., 2015; Zhang Biao et al., 2015). This method did not take into account the impact that the urban conditions may have on urban infiltration. In addition, urbanization has dramatically alerted the urban soil through sealing, intensive disturbance, deposition of building and daily rubbish, sedimentation of air dust, and infiltration of sewage (Zhao et al., 2007; Shaw et al., 2010). These processes damage and change the urban soil compared with the natural soil. It is important to understand scientifically the effects of urbanization on soil infiltration. Urbanization effects are typically evaluated along urban-rural gradients, which have been used in studies considering soil properties, forest soil heavy metals, polycyclic aromatic hydrocarbons and soil organic carbon (Pouyat and McDonnell, 1991; Pouyat et al., 2002; Wong et al., 2004; Zhang, 2004; Pouyat et al., 2008). Many results showed that soil organic matter, water-stable aggregates, cation exchange capacity, total nitrogen, total phosphorus and heavy metal concentrations (such as lead, copper, and nickel) increased from rural to urban zones (Zhang et al., 2003; Lu et al., 2009). In China, cities are usually sprawled through ring road development and different ring roads often represent the urbanization gradients (Huang et al., 2010; Zhai et al., 2017). Therefore, studying the urbanization effects on forest soil infiltration through the use of ring road-related gradients is available. Vegetation can improve the soil properties in various ways depending on different community composition (Bezemer et al., 2006; Yimer et al., 2006; Fu et al., 2010; Oldfield et al., 2014; Regüés et al., 2017). Many results showed that different vegetation composition had different impact on soil organic carbon storage, soil microbial community and soil quality (Guo and Gifford, 2002; Hooker and Compton, 2003; Gao et al., 2009; Merilä et al., 2010; Hou et al., 2012). However, there have been fewer studies on the effect of different vegetation composition on soil properties, especially in cities.

Until now, only a few studies on urban green space soil infiltration rates and influencing factors have been conducted (Winzig, 2000; Yang and Zhang, 2011; Wei et al., 2012), with less emphasis on soil infiltration characteristics of different forest types, different plant communities and different urbanization gradients. Changchun City in Northeast China has undergone rapid urbanization over the past decades. The urban vegetation coverage and soil have changed notably. Understanding the spatial distribution of soil infiltration of urban forests in Changchun and its relationships with urbanization are critical for planning a no-flood and sustainable city. Understanding the current situation of soil infiltration and its influencing factors can provide the theory base for urban forest management. The aims of this work were as follows: 1) describe the urban forest soil infiltration characteristics, 2) study the effect of urban forest types, urbanization gradients and plant communities on soil infiltration, and 3) discuss its influencing factors.

2 Materials and Methods

2.1 Study area

Changchun (43°05′–45°15′N, 124°18′–127°02′E), the capital of Jilin Province, is located in the northeastern plain of China. This region is characterized by a subhumid climate with a continental monsoon (Ren et al., 2013; Zhang Dan et al., 2015). The mean annual temperature is 4.8℃ and the mean annual precipitation is 569.6 mm. Nearly 70% of the annual precipitation is concentrated in the summer season. The city has witnessed a rapid urbanization and economic growth over the last twenty years. Its urban population has accelerated notably in recent decades with urban expansion that followed the form of concentric ring roads. The main urban area of Changchun had increased from 117 to 365 km^2, and the population increased from 2.20 million to 3.62 million during the period from 1994 to 2010 (Huang et al., 2009; Li et al., 2012). Urban waterlogging caused by the heavy precipitation and old urban drainage piping systems has become more frequent in recent years (Xiao et al., 1989; Xi et al., 2016). The geology of the region consists of Quaternary alluvial-diluvial deposits and the natural soil types in the study area are, mainly black soil, dark brown soil and meadow soil according to the Classification and codes for Chinese soil (National standard, GB/T 17296-2009) (Yang et al., 2011). The urban forest cover of the main urban area is 106.81 km^2, mainly composed of coniferous forest and broad-leaved forest (Zhang Dan et al., 2015). The common trees in Changchun includes *Armeniaca mandshurica*, *Pinus sylvestris* var. *mongolica*, *Pinus tabuliformis*, *Larix gmelinii*, *Salix babulonica*, *Populas alba* and *Ulmus pumila* (Zhai et al., 2017). The understory shrubs and grasses includes *Swida alba*, *Spiraea salicifolia*, *Amygdalus triloba* and *Poa annua*.

2.2 Soil sampling

The sampling area (43°43′–44°04′N, 125°07′–125°27′E) is primarily within the fifth ring road of Changchun, with an area of 524.06 km^2. Based on location, function and management objectives, urban forests are classified into five types (He, 2004): road forest (RF), attached forest (AF), landscape and relaxation forest (LF), ecological and public welfare forest (EF) and production and management forest (PF). A total of 191 representative sites were surveyed in Changchun (Fig. 1), which included 72 plots for RF, 73 plots for AF, and 46 plots for LF. According to the understory vegetation, the plots were divided into four types: trees with shrubs and

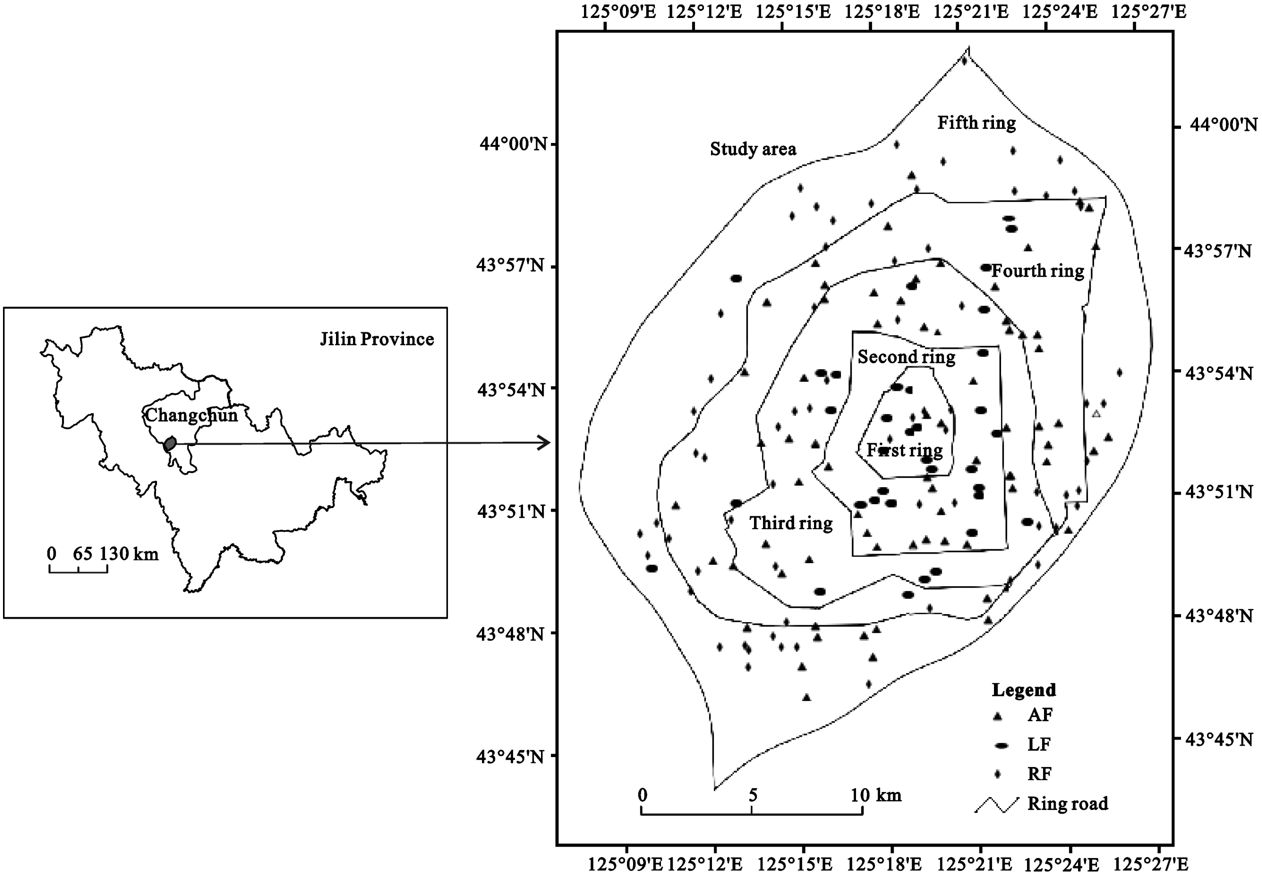

Fig. 1 Location of study area and sampling sites. RF, road forest; AF, attached forest; LF, landscape and relaxation forest.

grasses (FSG, 64 plots), trees with grasses (FG, 86 plots), trees with sparse grasses (FFG, 17 plots) and trees with bare land (FB, 24 plots). Field surveys were conducted from June to August in 2014. Each plant community plot was 400 m^2. Both the widths and lengths of the plots were normally 20 m and adjusted according to the situation. Urban soil compaction occurs primarily in the soil surface (Dornauf and Burghardt, 2000; Yang et al., 2005); thus, soils were sampled at a depth of 0–10 cm. Undisturbed soil cores were collected with standard core rings (height, 52.00 mm; diameter, 70.00 mm) to determine the soil water content, bulk density, and porosity. In addition, samples were taken from a depth of 0–10 cm to analyze the pH, organic matter and other properties. Each sample was replicated three times.

2.3 Soil property analysis

Soil physical and chemical properties were determined according to standard methods (Institute of Soil Science, Chinese Academy of Sciences, 1978; Lu, 2000). The antecedent soil water content (AWC) was determined by the oven drying method, and the bulk density (BD) was obtained from soil core rings. The total porosity (TP) was calculated from the bulk density and the particle density (d_s=2.65 g/cm^3) (Equation (1)), the capillary porosity (CP) was obtained from the intact soil core (Equation (2)), and the non-capillary porosity (NCP) was calculated from the total porosity and the capillary porosity (Equation (3)). Saturated soil water content (SSWC) (g H_2O/100 g dry soil) was determined by mass loss from saturated soil samples during oven drying at 105℃ to constant weight, and then it was calculated on a volumetric basis using the determined BD value. The soil pH was obtained with a glass electrode at a 1∶2.5 sample/water ratio. Soil organic matter content (SOC) was determined by acid-dichromate digestion. Aggregate stability (WAS) was determined using an adaptation of the wet sieving method (Yoder, 1936).

$$TP = \left(1 - \frac{BD}{d_s}\right) \times 100 \tag{1}$$

$$CP = W_c \times \frac{BD}{V} \times 100 \tag{2}$$

$$NCP = TP - CP \tag{3}$$

where TP is the total soil porosity (%), BD is the soil bulk density (g/cm^3), and d_s is the soil particle density (g/cm^3), CP is the soil capillary porosity (%), NCP is the soil non-capillary porosity (%), W_c is the soil capillary water content (%), and V is the volume of the soil core (cm^3).

The initial and final infiltration rate (cm/h) of soil was determined by the dual-ring method (Liu et al., 2007). According to the process of soil infiltration, we chose the mean infiltration rate for the first 3 min as the initial infiltration rate (IIR), and then chose the average infiltration rate for 0–15 min as the average infiltration rate of the stage I (AIRSI). Likewise, the average infiltration rate of stage II (AIRSII) was for the period of 15–30 min and the average infiltration rate of stage III (AIRSIII) was for the period from 30 to 60 min. The average infiltration rate of the final 3 min was taken as the steady infiltration rate (SIR). The average infiltration rate of the 0–60 min period was chosen as the overall average infiltration rate (AIR) (Wu et al., 2016). According to the criteria proposed by Kohnke (1968), the steady infiltration rates were categorized into seven levels: very slow (k_s≤0.1 cm/h), slow (0.1<k_s≤0.5 cm/h), slow to medium (0.5<k_s≤2.0 cm/h), medium (2.0<k_s≤6.3 cm/h), medium to fast (6.3<k_s≤12.7 cm/h), fast (12.7<k_s≤25.4 cm/h) and very fast (k_s>25.4 cm/h).

2.4 Data Analysis

The values of soil property were averaged for three samples from each plot. Pearson correlation coefficients were calculated to detect relationships between soil properties and infiltration variables. One-way analysis of variance (ANOVA; $P < 0.05$) was used to compare the differences between means. Principal component analysis (PCA) was used to determine the influencing factors. The SPSS 17.0 was used to carry out the analysis.

3 Results

3.1 Steady infiltration rate level

In our study, the steady infiltration rates were categorized into seven levels (Fig. 2). The steady infiltration rates of urban forest soils varied widely and ranged from 0.23 to 25.50 cm/h. The majority of infiltration rates were categorized as slow to medium, medium, medium to fast and fast. No very slow infiltration rate soil was in Changchun urban forest. Slow and very fast infiltration rates accounted for 2.00% of the samples. Medium

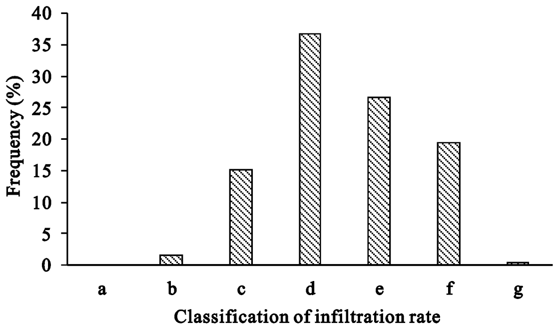

Fig. 2 Frequency of distribution of steady infiltration rate. a=very slow; b=slow; c=slow to medium; d=medium; e=medium to fast; f=fast; g=very fast

infiltration rate accounted for 37.00% of the samples and nearly 53.40% of the soil infiltration rates were lower than 6.30 cm/h (medium to fast infiltration rate).

3.2 Soil infiltration rate of different vegetation types beneath forests and different urban forest

As shown in Table 1, infiltration rate began with high values and decreased gradually to a final constant rate. The infiltration rates varied widely over infiltration stages. Moreover, the difference between the initial and final infiltration rate was large. The RF had higher mean values of IIR, SIR, AIR, AIRSI, AIRSII and AIRSIII than other urban forest types, and LF had the lowest values. The FSG had the highest values and FB had the lowest values. In our study, the infiltration rate of FFG was higher than FG in AF and LF but not in RF. As shown in Fig. 3A, the final infiltration rates of RF, LF and AF were not significantly different because large variations were observed in these urban forest types. However, significant differences in the infiltration rates were observed between FSG and FB (Fig. 3B). Compared with FB, the infiltration rates of FSG improved by 45.95%–102.18%. As shown in Table 1, trees with grasses or shrubs had higher values of AIR, AIRSI, AIRSII, AIRSIII and IIR than the trees with bare land under them.

3.3 Soil infiltration rate of gradients of urbanization

As shown in Fig. 4, the soil infiltration rate of LF in the second ring was the lowest and that in the third ring was the highest. The soil infiltration rate of RF in the first ring was the lowest and in the fourth ring was the highest. In addition, there were no significant differences

Table 1 Soil infiltration rates of urban forest soil

Type	Vegetation	IIR (cm/h)	SIR (cm/h)	AIR (cm/h)	AIRSI (cm/h)	AIRSII (cm/h)	AIRSIII (cm/h)
AF	FSG	24.34±20.81	9.57±6.14	12.01±9.07	17.76±14.68	12.85±9.49	10.02±6.45
	FG	15.21±20.09	5.84±5.65	7.47±7.81	10.23±12.67	7.12±7.40	5.89±5.95
	FFG	20.83±10.71	11.20±6.32	13.15±7.48	16.57±9.43	13.08±7.69	11.48±6.47
	FB	12.15±8.56	4.67±2.39	6.16±3.11	9.07±6.02	5.72±2.84	4.92±2.41
	MV	18.98±19.86	7.51±5.99	9.48±8.36	13.55±13.46	9.63±8.55	7.75±6.32
LF	FSG	22.88±19.79	9.22±4.97	10.74±8.12	15.83±11.44	11.23±6.69	9.61±5.49
	FG	14.15±10.80	6.56±5.22	7.98±6.02	10.80±8.58	8.21±6.55	6.93±5.44
	FFG	15.94±15.30	7.58±8.58	8.97±9.75	11.50±11.83	8.67±9.50	7.85±9.02
	FB	11.22±10.39	4.16±2.64	5.19±3.48	7.00±5.48	5.01±3.13	4.37±2.67
	MV	15.31±13.12	6.70±5.23	8.06±6.43	11.08±9.07	8.22±6.47	7.03±5.49
RF	FSG	22.84±21.72	9.17±6.68	11.35±8.41	14.99±11.85	11.17±8.30	9.51±6.96
	FG	20.03±22.72	8.20±7.39	10.66±9.91	14.65±15.61	10.34±9.62	8.72±7.83
	FFG	15.74±11.98	7.19±6.47	8.99±7.95	11.65±10.33	8.99±8.15	7.67±6.83
	FB	13.51±15.61	4.96±3.99	6.62±6.56	9.30±10.98	6.50±6.39	5.34±4.57
	MV	19.41±20.13	7.90±6.62	10.05±8.68	13.53±12.97	9.85±8.52	8.33±6.99

Notes: AF, attached forest; LF, landscape and relaxation forest; RF, road forest. MV is the average infiltration rates of different forest types. FSG, trees with shrubs and grasses; FG, trees with grasses; FFG, trees with sparse grasses; FB, trees with bare land. IIR is the mean infiltration rate for the first 3 min; AIRSI is the average infiltration rate of stage I for the period of 0–15 min; AIRSII is the average infiltration rate of stage II for the period of 15–30 min; AIRSIII is the average infiltration rate of stage III for the period of 30–60 min; SIR is the average infiltration rate of the final 3 min and AIR is the average infiltration rate of the 0–60 min period.

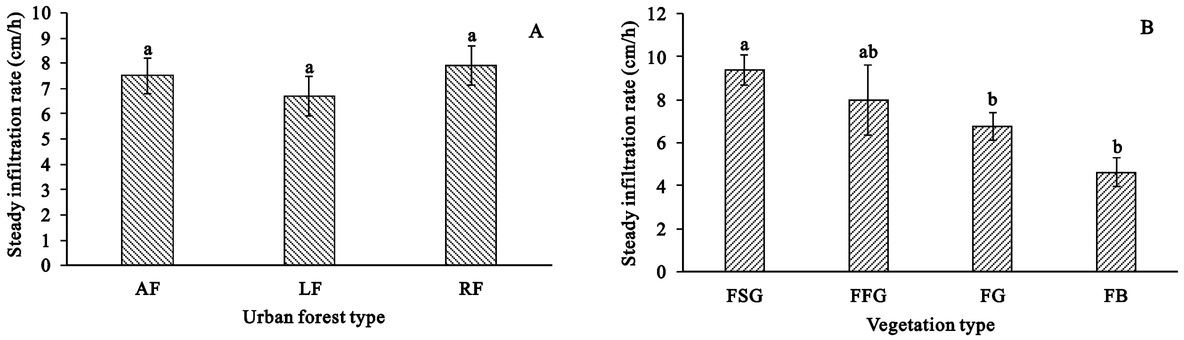

Fig. 3 Final infiltration rate for different urban forests (A) and vegetation types (B). Error bars indicate the standard error, a and b represent significant differences at a confidence level of 95%. AF, attached forest; LF, landscape and relaxation forest; RF, road forest. FSG, trees with shrubs and grasses; FFG, trees with sparse grasses; FG, trees with grasses; FB, trees with bare land.

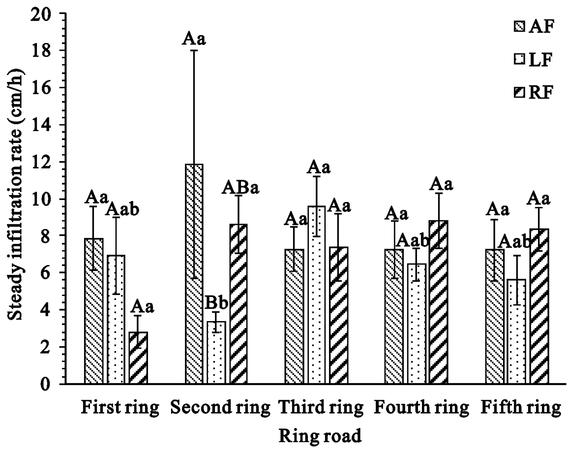

Fig. 4 Mean infiltration rates of different forest types in different urbanization gradients. A and B represent significant differences of different forest types in the same ring at the confidence level of 95%; a and b represent significant differences of the same forest types in the different rings at a confidence level of 95%. AF, attached forest; LF, landscape and relaxation forest; RF, road forest.

among the mean soil infiltration rates of AF and RF in the five rings. However, significant differences were observed among the mean soil infiltration rates of LF in the five rings. There were significant differences among the mean soil infiltration rates of these three types of urban forest just in the second ring. In the second ring, LF had the highest soil infiltration rate and soil infiltration rate of AF was close to RF.

3.4 Influencing factors of soil infiltration

In our study, the infiltration rates were correlated to the bulk density, total porosity, capillary porosity and saturated soil water content (Table 2). There were significant negative relationships between SIR and BD and significant positive relationships between SIR and TP, CP and SSWC. Principal component analysis (PCA) was applied to the aforementioned factors. As shown in Table 3, the eigenvalues of the first four PCs were great than 1 and the four components contributed to more than 77.79% of the total variance. The highly weighted parameters in PC1 were BD, TP, CP, AWC and SSWC. The BD had the highest loading value and was strongly

Table 2 Correlation matrix between infiltration rates and soil properties

Soil infiltration rate	pH	EC	BD	AWC	TP	CP	NCP	WAS	SOC	SSWC
IIR	–0.007	0.063	**–0.191****	0.068	0.191**	0.166**	0.021	0.088	0.059	0.141
SIR	0.031	0.067	**–0.300****	0.124	0.300**	0.245**	0.061	0.074	0.033	0.188**
AIR	0.013	0.071	**–0.296****	0.122	0.296**	0.240**	0.063	0.108	0.060	0.214**
ARISI	–0.007	0.063	**–0.260****	0.103	0.260**	0.224**	0.033	0.092	0.058	0.186*
ARISII	0.011	0.070	**–0.310****	0.132	0.310**	0.261**	0.049	0.094	0.053	0.205**
ARISIII	0.033	0.079	**–0.313****	0.131	0.313**	0.257**	0.063	0.076	0.047	0.195**

Notes: * indicates significant correlation and ** indicates highly significant correlation. EC, electrical conductivity; BD, bulk density; AWC, antecedent soil water content; TP, total porosity; CP, capillary porosity; NCP, non-capillary porosity; WAS, aggregate stability; SOC, soil organic matter content; SSWC, saturated soil water content; IIR is the mean infiltration rate for the first 3 min; AIRSI is the average infiltration rate of stage I for the period of 0–15 min; AIRSII is the average infiltration rate of stage II for the period of 15–30 min; AIRSIII is the average infiltration rate of stage III for the period of 30–60 min; SIR is the average infiltration rate of the final 3 min and AIR is the average infiltration rate of the 0–60 min period.

Table 3 Extracted components and contributing factors of infiltration rates by principal component analysis

Eigenvector	Principal component			
	PC1	PC2	PC3	PC4
BD	–0.947	–0.093	0.152	–0.061
TP	0.947	0.093	–0.152	0.061
CP	0.887	–0.252	0.173	–0.236
NCP	0.030	0.617	–0.574	0.531
pH	0.188	–0.487	0.160	0.456
EC	0.203	0.596	0.451	–0.116
SSWC	0.845	–0.144	0.016	0.031
WAS	–0.039	–0.018	0.591	0.657
AWC	0.775	–0.125	–0.083	0.066
SOC	0.306	0.708	0.036	–0.117
Eigenvalue	4.072	1.557	1.122	1.011
Cumulative variance explained (%)	40.660	56.580	67.610	77.790

Notes: PC, principal component; BD, bulk density; TP, total porosity; CP, capillary porosity; NCP, non-capillary porosity; EC, electrical conductivity; SSWC, saturated soil water content; WAS, aggregate stability; AWC, antecedent soil water content; SOC, soil organic matter content.

correlated with TP, CP, AWC and SSWC (Table 4). Thus, TP, CP, AWC and SSWC were eliminated, while BD was retained as a parameter that affected the soil infiltration capacity. In PC2, the highly loaded parameters included NCP, EC and SOC. The SOC had the highest loading value and was strongly correlated with NCP (*r*=0.154, Table 4) and EC (*r*=0.405, Table 4). Therefore, SOC was selected. In PC3 and PC4, NCP and WAS had the highest loading values. No significant correlation was found between NCP and WAS. So, NCP and WAS were chosen. In summary, the most critical parameters, as determined from the PCA, that would affect soil infiltration capacity were BD, NCP, WAS and SOC.

4 Discussion

4.1 Impact of vegetation cover on soil infiltration

A steady infiltration rate, equivalent to saturated hydraulic conductivity, is one of the important indicators to evaluate soil physical characteristics and a critical component of most urban runoff models. Soil infiltration is affected by various factors such as vegetation cover, soil texture and structure, soil organic matter, antecedent water content, management system, disturbance age and landscape position (Radke and Berry, 1993; Pitt et al., 1999; Kumar et al., 2012). Many previous studies have showed that there was a great difference in the soil infiltration rate of different land use and different functional urban green areas (Yang et al., 2008; Wei et al., 2012; Chen et al., 2014). There was wide variability in soil infiltration rates among different urban forest types in our study. Vegetation characteristics have important effects on soil infiltration capacity. In our study, the FSG had the highest values followed by FG, and FB had the lowest values (Fig. 3B). The infiltration rates in areas with shrubs and grasses were relatively higher because shrubs and grasses can loosen compacted soil and can aid in the formation of soil macropores and good soil structure (Meek et al., 1989; Wu et al., 2016). In addition, shrubs protected the soil

Table 4 Correlation matrix among the soil properties

Soil property	BD	TP	CP	NCP	pH	EC	AWC	SSWC	WAS	SOC
BD	1	–1.000**	–0.844**	–0.177*	–0.116	–0.172*	–0.635**	–0.688**	0.048	–0.226**
TP		1	0.844**	0.177**	0.116	0.172*	0.635**	0.688**	–0.048	0.226**
CP			1	–0.379**	0.176*	0.123	0.592**	0.700**	–0.031	0.128
NCP				1	–0.122	0.071	0.008	–0.096	–0.026	0.154*
pH					1	0.011	0.163*	0.213**	0.071	–0.191**
EC						1	0.076	0.052	–0.001	0.405**
AWC							1	0.700**	–0.030	0.116
SSWC								1	0.008	0.226**
WAS									1	0.059
SOC										1

Notes: BD, bulk density; TP, total porosity; CP, capillary porosity; NCP, non-capillary porosity; EC, electrical conductivity; SSWC, saturated soil water content; WAS, aggregate stability; AWC, antecedent soil water content; SOC, soil organic matter content.

from compaction. Alternatively, the infiltration rate was very low in urban forests with bare land because the soil was apt to be trampled by pedestrians. The infiltration rate of FFG was higher than FG in AF and LF, possibly because the infiltration capacity is decreased by grasses (Archer et al., 2002; Fischer et al., 2014). Thus, shrubs are better than grasses in the improvement of soil structure in urban greening. Therefore, in order to make full use of urban green space soil for rainwater reduction, a proper vegetation configuration is needed. For example, in urban greening, more shrubs and less lawns should be promoted.

4.2 Impact of urbanization on soil infiltration

In the past few decades, China has experienced a rapid and unprecedented process of urbanization, with urban areas expanding almost exponentially outwards in many cities in parallel with ring road construction. In China, different ring roads often represent the urbanization gradients (Huang et al., 2010; Zhai et al., 2017). During the process of urbanization, forests and soils were significantly influenced by human activities and large areas of urban forests have been occupied due to accelerating urbanization. Meanwhile, many afforestation movements such as ‘forest city’ or ‘eco-city’ have been initiated in cities due to citizens’ desire for a better quality of life (Bae and Ryu, 2015; Lv et al., 2016). Urban forest soil is affected not only by plant-soil interaction and afforestation but also by human activities such as trampling (Jim, 1998c; Hobbie et al., 2007). Our results indicated that there were no obvious differences in the steady infiltration rate of AF and RF among different ring roads. The steady infiltration rate of LF in the third ring was significantly higher than other rings. One reason for such differences might be that LF is mainly located in the semi-natural environments (such as public parks, forest parks, and historic sites). LF in the third ring were less disturbed, LF in the first ring and the second ring were intensively disturbed by people but LF in the fourth and fifth are under construction. Compared with LF, AF and RF are more closely impacted by humans. Therefore, the interference degree on AF and RF soil of different urban gradients might not differ greatly. To sum up, the impact of urbanization on urban soil infiltration is complex, and the mechanisms that drive this difference due to the complex factors controlling soil infiltration in urbanized regions still needs to be explored.

4.3 Impact of soil properties on soil infiltration

Soil water infiltration is a key process in the water cycle since it controls, inter alia, the surface water-groundwater relationship. The soil properties play a crucial role in this process. Many studies have demonstrated that the infiltration rate depends mainly on soil properties, such as initial moisture content, hydraulic conductivity, soil texture, porosity, swelling degree of soil colloids, organic matter content, and chemical properties (Saxton et al., 1986; Bagarello and Sgroi, 2004; Chai et al., 2007; Bormann and Klaassen, 2008; Fischer et al., 2014). Soil bulk density is one of the most important factors that influence infiltration capacity (Winzig, 2000; Yang et al., 2008). Our results also showed that the soil infiltration rate decreased with increasing bulk density. For example, at a soil bulk density of 1.44 g/cm^3, the infiltration rate was lower than 5.00 cm/h. In contrast, the bulk densities of soils that had higher infiltration rates were 1.19–1.35 g/cm^3.

Soil pores provide channels for water movement in the soil. If there is more connectivity between pores, the soil infiltration rate will be increased. Past studies have found that soil infiltration rates had significant positive linear correlations with the total porosity and non– capillary porosity (Yang and Zhang, 2011; Li et al., 2013). Our results showed that there were positive relationships between infiltration rates and soil total porosity and non-capillary porosity. Urban soils are frequently mixed with many gravel, coal cinders, construction waste and other artificial substances in city greening. The existence of gravel creates a number of macropores in soil, which easily form preferential flow that is mainly influenced by gravity and not capillary pores (Yang et al., 2008).

Compaction is the most serious form of the physical degradation in urban areas. Compaction usually leads to increases in bulk density and decreases in porosity and formation of a crust layer that prevents water infiltration into the surface soil (Bruand and Cousin, 1995; Jim, 1998a; Richard et al., 2001). In our study, the final infiltration rate decreased with increased soil compaction (Fig. 5). Furthermore, the final infiltration rate of non-compacted soil was significantly different from that of severely compacted soils. Specifically, the infiltration rate of non-compacted soil was 8.84 cm/h, and the infil-

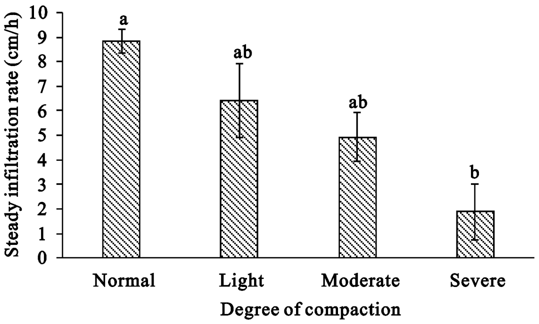

Fig. 5 Final infiltration rates of urban forest soil with different degrees of compaction. Error bars indicate the standard error, a and b represent significant differences at a confidence level of 95.00%. According to Yang and Zhang (2011), urban forest soil of Changchun can be categorized into five compaction levels: normal, d_s<1.30 g/cm^3; light, 1.30 g/cm^3≤d_s<1.40 g/cm^3; moderate, 1.40 g/cm^3≤d_s<1.50 g/cm^3; severe, 1.50 g/cm^3≤d_s<1.60 g/cm^3; extreme, d_s≥1.60 g/cm^3

tration rate of the severely compacted soil was 1.88 cm/h. Generally, urban green space soils are compacted mainly by mechanical compaction in urban greening and human trampling. Compaction affects root growth of the plant and inhibits water penetration into the soil, causing waterlogging in urban areas (Yang and Zhang, 2011). Therefore, in the process of urban greening the measures should be taken to loosen the soil and avoid compaction.

In the process of urbanization, soils are typically degraded by a wide range of modifications including vegetation clearing, topsoil removal, grading, and compaction. These practices significantly influence soil physical characteristics (Jim, 1993, 1998b; Alaoui et al., 2011) and ultimately lead to the loss of critical soil- mediated ecosystem services such as storm water mitigation (Pitt et al., 2008), carbon storage (Chen et al., 2013), and net primary productivity (Milesi et al., 2003). Many studies showed that soil organic amendments could help the formation of soil aggregates and improve the soil structure and therefore has a significant effect on the increasing infiltration rates (Boyle et al., 1989; Martens and Frankenberger, 1992; Arvidsson, 1998; Celik et al., 2010; Brown and Cotton, 2011). In our study, there were positive relationships between soil organic matter and infiltration rate. Thus, in the process of urban green spaces management and maintenance, returning the litter to the green land, increasing the surface organic coverage or organic manure fertilizer to increase the infiltration rate should be advocated.

4.4 Comparision of urban greenspace soil infiltration rate with other cities

Compared with other studies in China, the percentage of medium soil infiltration rate in Changchun (37%) was similar to Hefei (Wei et al., 2012) and Shanghai (Nie et al., 2008) greenspaces. The percentage of soil infiltration rate less than medium to fast in Changchun (53.40%) was similar to Nanjing (Yang et al., 2008) and lower than Hefei city (78.90%) and Shanghai city (84.21%) (Wei et al., 2011). The soil infiltration rates of Changchun urban forest ranged from 0.23 to 25.50 cm/h. Soil infiltration rates of residential lawns in central and south-central Pennsylvania ranged from 0.40 to 10.00 cm/h and 0 to 41.80 cm/h, respectively (Hamilton and Waddington, 1999; Woltemade, 2010). The urban soil infiltration rates in Oconomowoc, Wisconsin, ranged from 0 to 38 cm/h (Pitt et al., 1999) and in Montgomery County, Virginia, ranged from 0.40 to 2.30 cm/h (Chen et al., 2014). Thus, urban soil infiltration rates varied largely for soils from different regions. Soil texture differed due to development under different soil parent materials (Bormann and Klaassen, 2008). Even in the same city there may be some inhomogeneous soils. Moreover, green space management, area and distribution also differed from one city to another. These all might have impact on soil infiltration.

5 Conclusions

In this study, detailed field experiments were conducted using double ring infiltrometers to examine the effects of urban forest type and community composition on soil infiltration rates within the fifth ring road of Changchun. The steady infiltration rates of urban forest soil were highly variable and ranged from 0.23 to 25.50 cm/h. Almost 50% of the soil infiltration rates were very low and it showed that the urban forest soil infiltration capacity of Changchun was worse. Soil infiltration rates of road forest in the infiltration process were higher that attached forest and landscape and relaxation forest. Urbanization had different influences on soil infiltration of different urban forest types. Landscape and relaxation forest soil which was strongly disturbed by the local people had the lower infiltration rate. The impact of urbanization on soil infiltration of the attached forest and road forest might be not obvious. Large variations in the final infiltration rate were observed with different vegetation patterns. Trees with shrubs and grasses had the highest infiltration rates and trees. Large variations in the final infiltration rates of urban forest soils were attributed to the effects of soil bulk density and porosity due to high human activity. Thus, the degree of compaction was the most important factor that affected the urban forest soil infiltration rate. Therefore, in urban green spaces construction and management, mechanical compaction and human trampling must be avoided, and proper vegetation configuration will improve the role of urban forest soil in mitigation runoff.

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