Asian Agricultural Research 2013, 5(7): 63 -66, 86

The Effect of the Soil Water Holding Capacity and Permeability under Different Patterns of Land Use in the Eastern Qilian Mountains

Jinmei ZHAO[1], Degang ZHANG[2], Changzhong LIU[2 *]

1. Forestry College, Gansu Agricultural University, Lanzhou 730070, China; 2. Grassland Science College, Gansu Agricultural University, Lanzhou 730070, China

Abstract This study investigated the effect of the soil water holding capacity and permeability under different land use patterns in the Tianzhu alpine region of the Eastern Qilian Mountains, and four land use patterns were selected, namely, natural grassland, rehabilitated land, oats land and perennial grassland. As time went by, different land use patterns imposed significant effects on the water holding capacity power and permeability. The soil bulk density was rehabilitated land(1.104 g/cm^3) > perennial grassland(1.061 g/cm^3) > oats land(1.011 g/cm^3) > natural grassland(0.781 g/cm^3); the soil overall porosity was natural grassland(68.196%) > oats land(60.606%) > perennial grassland(58.93%) > rehabilitated land(57.5%); the natural grassland had the most water holding capacity power and soil steady infiltration rate(681.966 t/hm^2 and 3.02 mm/min), while the rehabilitated land had the least(575.005 t/hm^2 and 1.004 mm/min). In terms of soil water-holding capacity and permeability, the natural grassland was the best out of these four use patterns while the rehabilitated land was the worst pattern. In other words, both oats land and perennial grassland had better water holding capacity power and permeability than the rehabilitated land.

Key words Soil water holding capacity, Soil permeability, Land use patterns, The Eastern Qilian Mountains

Land utilization that has a comprehensive effect on various human activities[1] brings the most direct and profound effect on the physical and chemical features of soil[2-3]. As research results have been revealed, soil structure can be improved through rational utilizations while irrational use of land will lead to soil deterioration[4] as well as soil and ecosystem damages[5]. Water holding capacity power and permeability are important soil physical features that are considered as major indices of soil moisture adjustment ability and water-holding capacity, and important factors of soil erosion at the same time[6]. Hence, it can provide scientific basis in terms of soil deterioration prevention, soil erosion and rational land use via studying water holding capacity power and permeability under different land use patterns. Currently, some scholars have conducted researches in particular regions in this field[7-9]. However, there are relatively fewer studies at alpine regions where featured special geography and climate and fragile eco-environment.

This research is conducted in the Eastern Qilian Mountains located in Qinghai – Tibet Plateau where there are a typical alpine ecosystem and fragile environment. Thanks to recent years' irrational land use in this region, it has caused serious soil deterioration, further soil erosion and has made the ecosystem even more fragile. Therefore, water holding capacity power and permeability in this region have been studied under different land use patterns in the hope of providing reference data regarding to water and soil conservation and ecosystem rehabilitation in fragile alpine regions.

Received: February 20, 2013　　Accepted: June 16, 2013
Supported by National Natural Science Fund Program (30960082).
* Corresponding author. E-mail: liuchzh@gsau.edu.cn

1 Materials and methods

1.1 Study area overview The study area is located in the Tianzhujinqiang River Valley of the Eastern Qilian Mountains, the altitude of the area is between 2 900 and 4 300 meters, the region is cold and wet with an average annual temperature of -0.1 ℃, an average monthly minimum temperature of -18.3 ℃ (January), an average monthly maximum temperature of 12.7 ℃ (July), and a positive accumulated temperature of 1 380 ℃. It has an annual sunshine duration of 2 600 h; its major rainfall form is orographic rain that mainly happens in July, August, and September. The annual average precipitation is 416 mm, and the annual average evaporation is 1 592 mm which is as 3.8 times as its precipitation; rain and heat over the same period, and there is a wide temperature difference and no absolute frost-free season in this region with only two distinct seasons, winter and summer. The soil layer in this region is relatively thinner at 40 -80 cm approximately. In addition, the soil properties from flood plain, terrace and highland are sub-alpine meadow soil, sub-alpine chernozem, sub-alpine chestnut soil, sub-alpine shrub meadow soil and alpine shrub meadow soil respectively.

1.2 Sample land settings Four land use patterns including rehabilitated land, oats land, perennial grassland and natural grassland were selected for the research in accordance with major use patterns and differences. Meanwhile factors that remain steady in most circumstances such as altitude and slope were given full considerations. Detailed information of sample lands is shown in Table 1.

1.3 Soil property measurement Three undisturbed areas were randomly selected for soil profile in each sample land in August, 2009; soil layer samples were taken three times from each three layers according to soil depth of 0 – 10 cm, 10 – 20 cm, and 20 – 30 cm respectively from the sample lands by the means of annulus-reamer method. These samples were sent to lab for measuring soil bulk density and porosity. The soil bulk density and porosity were measured by annulus reamer method, while soil permeability was measured via interior annulus-reamer method[10].

Table 1 General information of sample land

Land use patterns	Altitude m	Aspect	Slope (°)	Vegetation coverage//%	Vegetation height//cm	Land use details
Rehabilitated land	2 911	Sunny	20	52	17	Fencing natural recovery after the rehabilitation, lasting 4 a
oats land	2 911	Sunny	20	90	95	Plant Avena sativa in the fencing natural recovery rehabilitation land
Perennial grassland	2 911	Sunny	20	87	16	Plant perennial grass: Festuca sinensis, Poa pratensis, Elymus nutans and Bromus inermis etc. in the rehabilitated land.
Natural grassland	2 924	Sunny	18	96	4	Cold and wet grassland, mainly graze yaks and Tibetan Antelopes at a grazing rate of 4.8 capita/hm^2 approximately

1.4 Soil water retention measurement The calculation formula of soil maximum moisture retention power, non-capillary water capacity and capillary capacity is[11]:

$$W = 10\,000\ Ph$$

In the formula, W stands for water holding capacity power (t/hm^2); P stands for soil porosity(%); h stands for soil layer depth(m).

1.5 Statistic analysis The collected data is statistically analyzed by Excel and SPSS 13.0.

2 Results and analysis

2.1 The changes of soil bulk density and porosity From the perspective of soil vertical distribution, its bulk density increased in the line with the increase of soil depth, while the overall porosity decreased with increasing soil depth; capillary porosity and non-capillary porosity indicated no obvious changing patterns with soil depth increasing (see Table 2). From these changes of soil bulk density and porosity under different land use patterns, we can conclude that land use patterns have significant influence on its bulk density and porosity ($P < 0.05$). Furthermore, the rehabilitated land had the biggest soil bulk density (1.104g/cm^3), followed by perennial land (1.061g/cm^3), leaving natural grassland the last one (0.781 g/cm^3); the natural grassland had the biggest overall soil porosity (68.196%), followed by oats land (60.606%), leaving rehabilitated land the last one (57.5%); capillary porosity and non-capillary porosity range from 53.752% to 62.221% and 3.602% to 6.28% respectively. In addition, the capillary porosity is natural land > oats land > perennial grassland > rehabilitated land; the non-capillary porosity is natural grassland > oats land > rehabilitated land > perennial grassland.

Table 2 The soil bulk density and porosity under different land use patterns

Soil layer//cm	Use pattern	Bulk density//g/cm^3	Overall porosity//%	Capillary porosity//%	Non-capillary porosity//%
0 – 10	Rehabilitated land	1.090^a	57.971^a	51.418^a	6.550^{ab}
	oats land	0.973^c	61.839^b	56.353^b	5.393^a
	Perennial land	1.018^b	60.352^c	54.450^{ab}	5.900^a
	Natural grassland	0.746^d	69.350^d	60.291^c	9.059^b
10 – 20	Rehabilitated land	1.091^a	57.937^a	56.846^a	1.091^a
	oats land	0.977^c	61.719^b	57.96^{ab}	3.756^a
	Perennial land	1.059^b	59.005^c	55.593^a	3.411^a
	Natural grassland	0.797^d	67.645^d	60.060^b	7.585^b
20 – 30	Rehabilitated land	1.132^a	56.594^a	52.992^a	3.600^{ab}
	oats land	1.082^b	58.261^a	52.546^a	5.715^b
	Perennial land	1.107^a	57.433^a	55.939^b	5.715^b
	Natural grassland	0.799^b	67.594^b	66.311^c	2.224^a

Note: Different letters marked on the same soil layer indicate a magnificent difference at 5% level ($P < 0.05$).

2.2 The changes of water holding capacity power The maximum moisture retention capacity of soil decreased when the soil depth increased, and capillary moisture capacity and non-capillary moisture capacity showed no distinct changing patterns when the soil depth increased. The maximum moisture retention capacity of natural land is the best among these different land use patterns (681.966 t/hm^2), while the worst one is rehabilitated land (575.005 t/hm^2), in other words, the former was as 1.2 times as the latter; the capillary moisture capacity and non-capillary capacity ranged from 537.5 to 622.207 t/hm^2 and from 36.019 to 62.894 t/hm^2 respectively. In terms of capillary moisture capacity, natural grassland > oats land > perennial grassland > rehabilitated land, while as for non-capillary moisture capacity, natural grassland > oats land > rehabilitated land > perennial grassland, (Table 3).

2.3 The changes of soil permeability Under the effects of different land use patterns, the initial infiltration rates from the sample lands varied from 2.4 – 4.7 mm/min (Fig. 1), in an order as natural grassland > perennial grassland > oats land > rehabilitated land; the average infiltration rates ranged from 3.4 – 1.2 mm/min, in order, natural grassland > oats land > perennial grassland > rehabilitated land. Furthermore, the natural grassland had the highest steady infiltration rate (3.03 mm/min) while the rehabilitated land had the lowest (1.004 mm/min).

Table 3 The water holding capacity power under different land use patterns

Soil layer//cm	Use pattern	Maximum water holiday capacity//t/hm^2	Capillary water holiday capacity//t/hm^2	Non-capillary water holiday capacity//t/hm^2
0 – 10	Rehabilitated land	579.712^{a}	514.179^{a}	65.533^{ab}
	Oats land	618.385^{b}	563.532^{b}	35.090^{a}
	Perennial land	603.523^{c}	544.525^{ab}	58.998^{ab}
	Natural grassland	693.503^{d}	602.912^{c}	90.591^{b}
10 – 20	Rehabilitated land	579.367^{a}	568.459^{a}	10.908^{a}
	Oats land	617.195^{b}	579.635^{ab}	37.559^{a}
	Perennial land	590.049^{c}	555.934^{a}	34.114^{a}
	Natural grassland	676.452^{d}	600.602^{b}	75.850^{b}
20 – 30	Rehabilitated land	565.937^{a}	529.922^{a}	36.015^{ab}
	oats land	582.611^{a}	525.458^{a}	57.153^{a}
	Perennial land	574.331^{a}	559.385^{b}	14.946^{b}
	Natural grassland	675.942^{b}	663.106^{c}	22.242^{b}

Note: Different letters marked on the same soil layer indicate a magnificent difference at 5% level ($P < 0.05$)

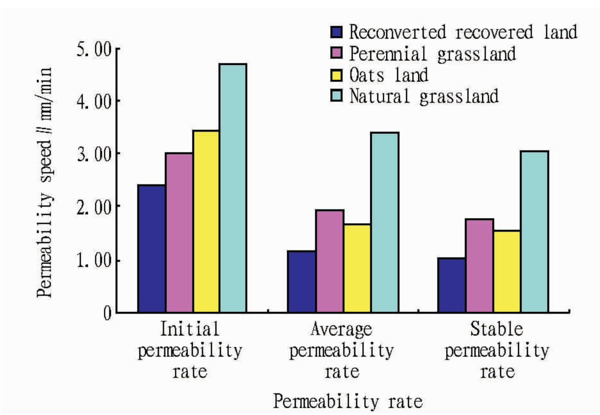

Fig. 1 The soil permeability under different land use patterns

From the different periods in the course of permeability, we can see (Fig. 2) that the infiltration rates from all sample lands gradually decreased over time, and the infiltration rates after 65mins witnessed an average decrease of 46.01% compared with the rates of the first two mins of the process of permeability. In each period, the natural grassland had the highest average infiltration rate out of other three land use patterns, whilst the rehabilitated land had the lowest one. What's more, the infiltration rate of the natural grassland in the first two mins was 4.69 mm/min, 3.025 mm/min after 65 mins of the permeability in comparison to 2.39 mm/min and 1.003 mm/min respectively of the rehabilitated land, which dropped 49.1% and 66.8% compared with the former in each corresponding period; the perennial grassland had a higher infiltration rate than the oats land in the first three minutes, however, it became lower than the latter after the first three mins, and their infiltration rate within the first two mins were 3.42 mm/min and 2.98 mm/min respectively, and dropped to 1.51 mm/min and 1.74 mm/min after 65mins, which were 27.08%, 36.46% and 50.01% lower than natural grassland in each corresponding period.

To sum up, it can be seen from the soil permeability experiment that the natural grassland had the highest rate in term of initial infiltration rate, average infiltration rate and steady infiltration rate which indicates a best performance of soil permeability capacity, followed by the perennial grassland and the oats land respectively, while the rehabilitated land performed the worst permeability capacity, having the lowest initial infiltration rate, average infiltration rate and steady infiltration rate.

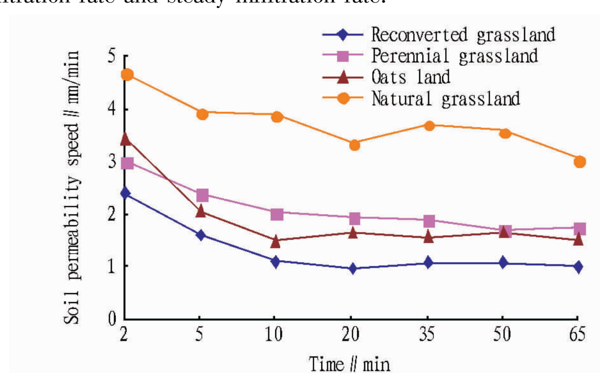

Fig. 2 The process of soil permeability under different land use patterns

3 Discussion

3.1 The effects on soil bulk density and porosity under different land use patterns The soil bulk density and porosity are the most important Indices of physical features of soil[12]. Both two will change in line with particular patterns when they are influenced under different use patterns[13]. The sample lands using different use patterns brought huge effects on the soil bulk density and porosity ($P < 0.05$). In the four land use patterns, the natural grassland had the highest vegetation coverage and a dense root system as well as a high organic content[14] which maintain healthy soil physical features such as lower bulk density and bigger porosity of natural grassland. Because of serious soil deterioration caused by previous cultivation that made the rehabilitated land seriously disturbed and damaged, the soil ecosystem had yet recovered to a satisfactory condition in the short term[15]. Hence, unhealthy soil physical features like poor bulk density and porosity were found in the rehabilitated land resulting from the lowest vegetation coverage and a scattered and few root systems as well as sealing soil situation. As for the oats land and the perennial land, thanks to increased vegetation coverage and improved root system by planting grass, the condition of related physical features were effectively recovered and improved[16]. In other words, the soil bulk density had decreased and the soil porosity had increased which showed similar results as the research conducted by Zhao Xiaodu *et al*[17].

3.2 The effects on water holding capacity power under different land use patterns The water holding capacity power depends on the soil density and porosity of certain soil depths[18-19]. Low soil bulk density means porous soil. In this case, the soil porosity will increase, guaranting more powerful water holding capacity capacity. However, high soil bulk density means sealing soil, and decreased soil porosity which makes less room for water-holding that results in a less powerful moisture retention capacity[20]. Therefore, the soil bulk density and porosity influenced under different land use patterns have directly reflected effects on the water holding capacity capacity imposed by land use patterns[21]. The lowest soil bulk density and the largest soil porosity were observed in the natural grassland, which means it had the best moisture retention capacity. The poorest soil bulk density and porosity were found in the rehabilitated land, which means it has the poorest water-holding performance; the situations of the oats land and the perennial grassland were better than the rehabilitated land but worse than the natural grassland, which means their water-holding capacities were between the rehabilitated land and the natural grassland.

3.3 The effects on soil permeability capacity under different land use patterns It is closely linked between soil permeability capacity and its physical features[22-23]. Therefore, the effects on the soil permeability under different land use patterns are resulting from the influences on the soil physical features such as soil bulk density and porosity especially imposed by land use pattens. Different land use patterns can significantly affect the soil permeability in terms of four related indicators including initial infiltration rate, average infiltration rate, steady infiltration rate and the process of infiltration of different time periods. Soil permeability of the natural grassland performed best, followed by the perennial grassland and the oats land. In addition, the rehabilitated land had the lowest rates concerning initial infiltration rate, average infiltration rate, and steady infiltration rate and therefore had the worst soil permeability capacity.

4 Conclusion

Different land use patterns have huge effects on the soil bulk density and porosity, water holding capacity power and soil permeability in the alpine regions. Generally, the natural grassland had low soil bulk density, large soil porosity, better water-holding and permeability capacity that can effectively reduce and prevent rainwash and soil erosion to a large extent; the soil ecosystem of the rehabilitated land had not been well improved within a short period, so its water-holding and permeability capacities were the worst with highest soil bulk density and smallest soil porosity. It is prone to have rainwash and soil erosion after raining which is adversable to the soil erosion prevention. The soil ecosystem of the oats land and the perennial grassland that previously were rehabilitated lands was greatly improved after being planted oats and perennial grass. Their soil bulk density and porosity, moisture retention capacity as well as permeability recovered to a better condition than the rehabilitated land, which indicated that rehabilitation in the alpine regions can effectively reduce local soil erosion and bring positive and significant effects on the recovery of local ecosystem.

References

[1] TURNER BL, MEYER WB, SKOLE DL. Global land-use land-cover change-towards an integrated study[J]. AMBIO, 1994, 23(1): 91-95.
[2] QIU LP, ZHANG XC. Effects of land use on soil properties in Ziwuling Region[J]. Journal of Natural Resources, 2006, 21(6): 966-972.
[3] MA Q, ZHAO GX. Effects of different land use types on soil nutrients in intensive agricultural region[J]. Journal of Natural Resources, 2010, 25(11): 1834-1844.
[4] CLAUDIO Z, ANNALISA C, FRANCO P. Soil degradation by land use change in an agropastoral area in Sardinia (Italy)[J]. CATENA, 2010, 83(1): 46-54.
[5] LIU CL, SHAO MA. Soil hydraulic properties and their influence on soil content under different land uses in Liudaogou watershed of Loess Plateau[J]. Chinese Journal of Applied Ecology, 2008, 19(11): 2400-2407.
[6] ZHAO YY, WANG YJ, WANG YQ, *et al*. Effects of structures of plantation forests on soil infiltration characteristics in source water protect areas in northern Chongqing City[J]. Acta Ecologica Sinica, 2010, 30(15): 4162-4172.
[7] LIU GL, FAN SH, QI LH, *et al*. Soil infiltration characteristics of different Phyllostachys pubescens forest[J]. Journal of Soil and Water Conservation, 2008, 22(6): 44-47, 56.
[8] WANG YQ, WANG YJ. Soil water retaining capacity and infiltration property of typical forests in the Jinyun Mountain[J]. Journal of Beijing Forestry University, 2006, 28(3): 102-108.
[9] DUAN WB, YAN YQ, ZHAO YS. Spatial distribution characteristics of soil infiltration capacity in water conservation forest of Larix gmeliniin Lianhua Lake Reservoir Area[J]. Journal of Natural Resources, 2010, 25(12): 2081-2090.
[10] Institute of Soil Science, Chinese Academy of Science. Determination of soil physical properties[M]. Beijng: Science Press, 1978: 147-148.
[11] SUN YH, ZHANG HJ, CHENG JH, *et al*. Soil characteristics and water conservation of different forest types in Jinyun Mountain[J]. Journal of Soil and Water Conservation, 2006, 20(2): 106-109.
[12] WEI Q, ZHANG QL, DAI HY, *et al*. Soil characteristics and water conservation of different forest types in Daqing Mountain[J]. Journal of Soil and Water Conservation, 2008, 22(2): 111-114.
[13] XU N, WU ZL, LI ZL. Comparative studies on soil bulk density and underground roots biomass under different land use types in northwestern Yunnan Province[J]. Journal of Anhui Agri Sci, 2008, 36(5): 1961-1963.
[14] YANG CD, LONG RJ, CHEN XR, *et al*. Characteristics of carbon, nitrogen and phosphorus density in top soil under different alpine grasslands on the Eastern Qilian Mountains[J]. Chinese Journal of Grassland, 2008, 30(1): 1-4.
[15] WEI XH, XIE ZK, DUAN ZH. Vegetation rehabilitation and soil moisture control in abandoned plowlands on Western Loess Plateau[J]. Journal of Desert Research, 2006, 26(4): 590-595.

(To page 86)

7) is the highest one, followed by provincial (Model 2) and municipal governments (Model 4). Although the evaluation score in natural reserves in state forestry department is high, it performs poorly in financial management, which is because that such natural reserve spends little money in protection management. Most natural reserves, managed by township or forestry department, have the lowest mark, while the ownership and other management modes are similar, which is compatible with the reality. (Fig. 2)

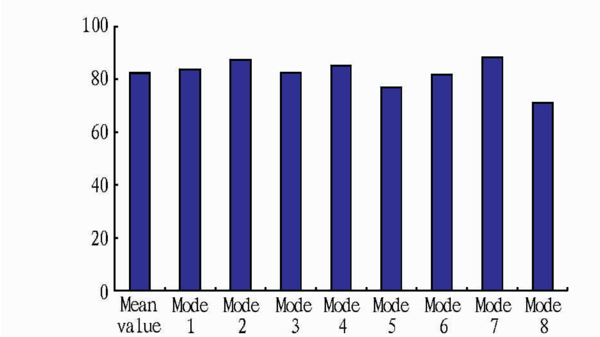

Fig. 2 The score of effective management of different manage modes in national natural reserve

(3) In natural reserves of each level, the natural reserve, directly managed by government, performs better than other departments in aspects such as management foundation and management coordination capacity, but was worse in community coordination, ecological tourism management and supervision.

(4) Considering the evaluation factors, plan design, resource management and ownership have the highest score, 94, 89 and 87 respectively, while the expenditure management, ecological tourism management and supervision have the lowest score, 51, 69 and 74. Each mode shows similar changes, which is related to the general plan, feasibility study and project construction.

4 Discussions

Classification management is an essential part of the natural reserve in China. However, generally speaking, there are four levels of management, and the differences among each management mode are reflected clearly. In order to improve the effectiveness of natural reserve management, it is necessary to improve the management system of nature reserve. The best mode is to let government directly set up management organization and ask the third party to supervise. This study only discusses the national natural reserves managed by forestry system. It is essential to include the regional nature reserve into study in future.

References

[1] The National Environment Protection Agency, Ministry of Forestry, *et al*. The plan of biodiversity protection action in China [M]. Beijing: China Environmental Science Press, 1995. (in Chinese).

[2] Ministry of Environmental Protection. Annual report of the statistics of natural protection areas [M]. Beijing: China Environmental Science Press, 1995. (in Chinese).

[3] OUYANG ZY, WANG XK, MIAO H, *et al*. Problems of management system of China's nature preservation zones[J]. Science & Technology Review, 2002 (1):49 –52. (in Chinese).

[4] WANG XP. Discussion on management system of protected areas [J]. Journal of Plant Resources and Environment, 1998, 7(1), 49 – 53. (in Chinese).

[5] ZHOU L. Conception and feasibility of joint management system of wild animals in natural reserve of China [J]. Journal of Central South Forestry University, 2004, 24(6):13 – 17. (in Chinese).

[6] HAN NY. Study on sustainable management policies of China's nature preservation zones [J]. Journal of Natural Resources, 2000, 15(3):201 – 207. (in Chinese).

[7] WANG J, LI XK. The deficiency and perfection of management system of China's nature preservation zones [C]//China Association for Environment and Resources Law(CAERL). Study on legal construction for forestry, forest and wildlife resources protection. The papers of Chinese environmental and resource law of 2004. 2004: 802 –805. (in Chinese).

[8] ZHOU K, HOU JR. Legislative improvement for natural reserve protection zones classification system in China [J]. Journal of Capital Normal University(Social Science Edition), 2007(2):58 –63. (in Chinese).

[9] GE HQ. The perfection of legal system for China's nature preservation zones under the background of public management [C]// China Association for Environment and Resources Law(CAERL). Ecological civilization and environmental resource law. The papers of Chinese environmental and resource law of 2009. 2009:342 –345. (in Chinese).

[10] XIA SM, YAN XW, XI K, *et al*. Management system of Chinaś nature reserve areas [J]. Journal of Zhejiang Forestry College, 2009, 26(1):127 – 131. (in Chinese).

[11] YU JH, WU LF. Problems and countermeasures in management of nature reserves in China[J]. Chinese Journal of Ecology, 2003, 22(4):111 –115. (in Chinese).

[12] ZOU LM. A rustic opinion on the perfection of management system and legislative problems in Chinaś nature reserve areas [J]. The Journal of Harbin Committee School of the CCP, 2007, 49(1): 86 –88. (in Chinese).

[13] LI Z, TANG XP, LI Y, *et al*. LY/T 1726 –2008 Evaluation of vituous management of Jiulianshan National Nature Reserve[M]. Beijing: Standards Press of China, 2008. (in Chinese).

(From page 66)

[16] HAN YW, HAN JG, ZHANG YW. Effects on soil physical properties of forages and crops in the agro-pastoral transitional zone of north China[J]. Acta Agrestia Sinica, 2002, 10(2): 100 –105.

[17] ZHAO XS, BI YF, SUN T, *et al*. Soil physical properties of artificial grassland on sloping fields of the Jinsha River Basin[J]. Journal of Yunnan Agricultural University, 2007, 22(5): 726 –735.

[18] CHAI YF, WANG EH, CHEN XW, *et al*. Study on soil water-holding capability and permeability of black soil under vegetation restoration [J]. Journal of Soil and Water Conservation, 2008, 22(1): 60 –64.

[19] LI H, FAN SF, ZHANG GC, *et al*. Characteristics of soil water-holding and soil porosity under different tree species after conversion of cropland to forest in the loss hilly region[J]. Bulletin of Soil and Water Conservation, 2010, 30(1): 27 –30.

[20] LI Z, WU PT, FENG H, *et al*. Simulated experiment on effects of soil bulk density on soil water holding capacity[J]. Acta Pedologica Sinica, 2010, 47(7): 611 –620.

[21] LI Z, WU PT, FENG H, *et al*. Simulated experiment on effect of soil bulk density on soil in filtration capacity[J]. Transactions of the CSAE, 2009, 25(6): 40 –45.

[22] PAN Y, LU DQ. Effects of soil bulk density on characteristics of soil infiltration[J]. Journal of Irrigation and Drainage, 2009, 28(2): 59 –67, 77.

[23] ZHANG CS, FAN SH, GUAN FY, *et al*. Soil infiltration characteristics and its influencing factors under *Phyllostachys edulis* forests in northern Fujian Province[J]. Scientia Silvae Sinicae, 2009, 45(1): 36 –42.