Land use effect on surface runoff and soil loss: results of plot-based experiment along east-west gradient in subtropical China

ABSTRACT

Surface runoff and soil loss were monitored in six land use types: secondary broadleaved mixed forest (BL), coniferous plantation (CF), extensively managed bamboo plantation (EB), intensively managed bamboo plantation(IB), economic forest(EF) and farmland (FL) in the east (Fuyang, Zhejiang Province), central (Pingjiang, Hunan Province) and west (Muchuan, Sichuan Province) of China. The results showed that (1) there were significant differences of surface runoff among the land use types. The surface runoff and runoff coefficient of FL ranked highest, followed by EB, then CF, IB and EF, with BL as the lowest. The surface runoff and runoff coefficient of FL was about 2-7 times of that of BL. (2) the effects were similar of land use type on the soil loss: the BL had the lowest soil loss, followed by CF, EB, IB and the highest in FL.(3) The characteristics of soil erosion for different land use types were significantly different along the gradient from east to west. The surface runoff coefficient and soil loss on the eastern China was significantly lower than that on the west, which may be attributed to the different natural conditions, social and economical development stage and the resources investment into soil and water conservation.

Keywords: Land use; surface runoff; soil loss; subtropical China

1. INTRODUCTION

Surface runoff and soil loss are important processes of soil degradation, resulting in significant problems to the environment and land productivity [1-2]. Land use type and land cover are considered the most important factors affecting the intensity and frequency of runoff flow and surface soil erosion[3-6]. The climatic factors, especially precipitation, landform conditions and soil conditions have also great effects on surface runoff and soil loss. However, these factors, compared with land use, are uncontrollable or unmanageable artificially. Therefore, land use planning has been given a high priority in soil erosion control in ecologically sensitive areas in China. Studies in a wide variety of environment conditions have shown that surface runoff and sediment yield decrease exponentially as the vegetation cover rate increases[6-9]. Unreasonable land use accelerates soil erosion and consequently, exacerbates environment deterioration and land degradation[10-12]

The subtropical zone extends from the east coastal area to the west inland area, covering a quarter territory of China. Across this zone, the major land use types are forest land and agricultural land. The agricultural land is mostly covered with annual crops, while forest land is mostly composed of broadleaf forests, conifer forests, economical forests and bamboo forests. The effect of vegetation types on soil and water conservation has been given a great emphasis on sustainable development and ecological construction in ecologically fragile regions. Much work has been conducted to explore the association between land use type and soil erosion control. These researches were traditionally confined to one or two major forest types, or other vegetation types. There were also some works focusing on specific location with different land cover types. Extensive assessment to land use effects on soil erosion in large areas may provide overview information[13-15], therefore, to gain insight in the process and to develop strategies for soil and water conservation, more detailed field experimental data that accurately quantify soil loss are needed[16].

In our research work, runoff plots were established in selected locations along east-west gradient across subtropical China, and surface runoff and soil loss were monitored for the major vegetation types typical in subtropical region in China, including broadleaf, conifer, bamboo, cash tree and farmland. The primary objective of this study is to quantify the difference in annual runoff and soil loss among different vegetation types along east-west gradient across subtropical China. A second objective is to provide plot-level on-site data for soil loss modeling at regional scale in subtropical China.

2. EXPERIMENT SITES AND METHODS

2.1 Experiment sites

The work was conducted in three sites along east-west gradient across subtropical China. They were Fuyang of Zhejiang, representing east coastal area, Pingjiang of Hunan, representing central area, and Muchuan of Sichuan, representing west inland area. Their natural conditions are as follows.

Fuyang (29°44′-30°12′N，119°25′-120°19′E) is located in the northwest of Zhejiang Province. The landform is mostly mountains or hills with forest coverage of 66.8%. The climate is typical subtropical maritime monsoon, with annual mean air temperature of 16℃, and annual precipitation of 1388mm.

Pingjiang (28°25′-29°60′N, 113°10′-114°9′E) is located in the northeast of Hunan Province. The landform is characterized with mountains and hills, with forest coverage of 60.1%. This region belongs to transition zone from central subtropical to north subtropical climate. The climate is continental monsoon, with annual air temperature of 16.8℃ and annual precipitation of 1450mm.

Muchuan (28°75′-29°08′, 103°70′-104°12′E) is located in the southwest of Sichuan Province. This region is also mountainous, with forest coverage of 66.2%. It belongs to typical inland subtropical monsoon climate, mean annual air temperature of 17.3℃ and mean annual precipitation of 1332mm.

2.2 Land use types

The major vegetation types in the subtropical region were selected for the study. They were broadleaved mixed forest (BL), coniferous plantation (CF), extensively managed bamboo plantation (EB), intensively managed bamboo plantation (IB), economic forest (EF) and farmland (FL). The dominant species in BL includes Cyclobalanopsis glauca (Fuyang site), Quercus fabric (Fuyang site), Rhododendron stamineum (Pingjiang site), Cinnamomum wilsonii (Muchan site) and etc. BL was mature or pre-mature with the canopy density higher than 0.7. CF includes Cunninghamia lanceolata (Fuyang and Pingjiang) and Metasequoia sequoia (Muchuan site) with the canopy density higher than 0.7 also. Bamboo includes Phyllostachys pubescens (Fuyang and Pingjiang) and Sinocalamus affinis (Muchuan site). In EB, the stand density is around 2250 culms per hectare and the averaged diameter at breast height (DBH) between 8 cm and 9 cm for Phyllostachys pubescens. Weeding is implemented periodically but no fertilization. In IB, the stand density is around 2700 culms per hectare and the averaged DBH between 9 cm and 10 cm for Phyllostachys pubescens. Both weeding and fertilization are applied periodically. FL is annual crops including water melon (Fuyang site), peanut

(Pingjiang site) and corn (Muchuan site). The topography of all land cover types is similar with a slope angle of about 20°.

2.3 Runoff plots

Surface runoff and soil loss were measured using the runoff plots. Four runoff plots were established in each land use type across the three sites. Each runoff plot was 5 m in width and 20 m in length with the width side parallel to the contour lines and the length side vertical to the contour lines. The plot borders were made of brick and cement walls, and were about 15-20 cm above the soil surface to prevent runoff water from flowing into the plot from the surrounding areas. A collecting trough, 30cm in depth, 30cm in width at bottom and 50cm in width at top, was constructed with cement at the downslope end of the plot and covered with a plastic sheet to prevent direct entry of rainfall[17]From this collecting trough, runoff and eroded sediments were channeled into the collecting tanks. A collecting tank, all 1m in width, depth and length, was constructed at the lower boarder of each runoff plot. All sediment and surface runoff from the plot enter the collecting tank during each rainfall event. Volume of surface runoff was calculated by measuring the height of the water in the collecting tanks. A sample of 500 ml was taken from the tank after thorough mixing to bring all the sediments into suspension. The sample was taken to the laboratory where the sediment was filtered, oven-dried at 100℃ for 12-24h and weighed. For each rainfall event, runoff volume and sediment loss from the plot were calculated. One or two rain gauges were placed at each site for rainfall measurement.

2.4 Data analysis

The total annual runoff, annual runoff coefficient and annual soil loss were calculated based on 12 months' monitoring for each runoff plot in the three sites. They were calculated with the Eqs. 1, 2 and 3[18].

$$R = \frac{\sum_{i=1}^{n} V_i}{S} \times 1000 \qquad \text{Eq.1}$$

$$RC = \frac{R}{P} \times 100\% \qquad \text{Eq.2}$$

$$SL = \frac{\sum_{i=1}^{n} \rho_i V_i}{S} \times 10 \qquad \text{Eq.3}$$

Where R is annual runoff (mm); RC is annual runoff coefficient (%); SL is annual soil loss (kg/ha.yr); i is the number of rainfall event through the study period (i=1, 2,……, n); Vi is the surface runoff volume at the ith rainfall event (m3); ρi is the sediment content at the ith rainfall event (kg/m3); S is the plot area (m2); P is the total precipitation during the study period.

One-way ANOVA was applied to analyze the annual runoff, annual runoff coefficient and annual soil loss among different land covers within each site, and different sites for each land use type. Means were compared using the least significant difference (LSD) test for differences in annual runoff, runoff coefficient and annual soil loss. Results were considered significant at $P < 0.05$. Data were analyzed with SPSS program V.18.

3. RESULTS AND DISCUSSION

3.1. SURFACE RUNOFF RELATED TO LAND USE TYPES

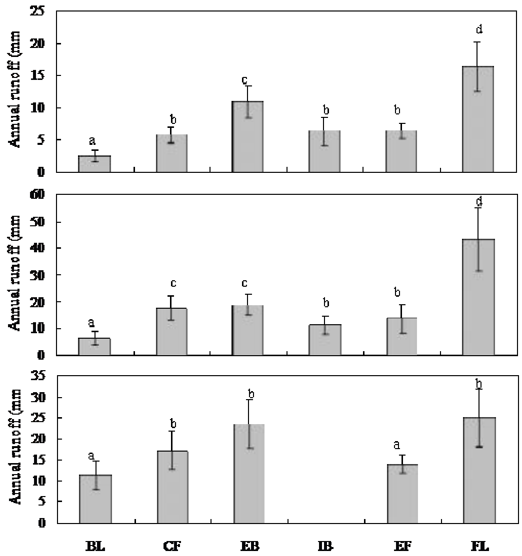

Fig. 1 Annual runoff for six land use types in east (Fuyang of Zhejiang, top panel), central (Pingjiang of Hunan, middle panel) and west (Muchuan of Sichuan, bottom panel).

*Test drugs: significant from normal control, * P < 0.05; ** P < 0.001*

Mean ± S.E.M = Mean values ± Standard error of means of six experiments

Fig. 1 shows the annual runoff for the different land use types in the three sites. The lowest annual runoff occurred in BL and the highest in FL for all the three sites with the runoff in FL 2.2 times and 6.7 times higher than other five land use types. The annual runoff for BL significantly lower than all the other land use types in the three sites except EF in Muchuan site, and that for FL significantly higher than all the other land cover types in Fuyang and Pingjiang sites. The ranking of the land use type in annual runoff was slightly different among the study sites, however, the order of the annual runoff can be approximately arranged as BL<IB<EF<CF<EB<FL.

The annual runoff is affected significantly by the annual precipitation at the site, resulting in incomparability of annual runoff between different sites with varied precipitation. To eliminate the effect of annual precipitation on runoff magnitude, the annual runoff coefficient for each site was calculated and presented in Fig. 2. Generally, the annual runoff efficient exhibited a similar pattern as the annual runoff with the order of BL<IB<EF<CF<EB<FL, identical among the three sites. The annual runoff coefficient for FL was the highest, implying the water holding capacity of farmland significantly lower than forests. Among the forest types, BL had the lowest annual runoff coefficient with a range from 0.2% to 1.1% in the three sites, exhibiting the highest water holding capacity. The conifer, bamboos and cash trees had pretty low annual runoff coefficient ranging from 0.5% to 2.3% depending on site and forest types, presenting pretty good water holding capacity.ase letters. Sample table format is given below.

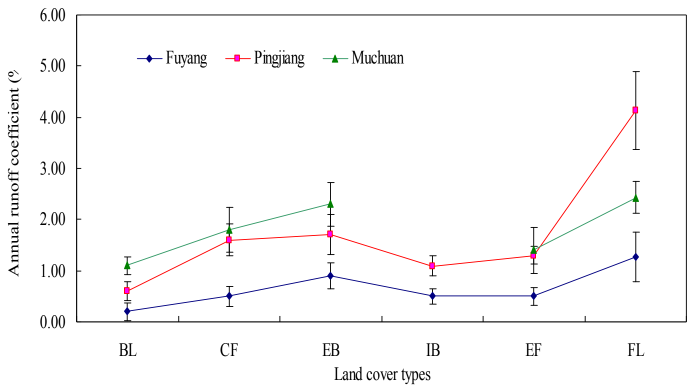

Fig.2 Annual runoff coefficient of six land use types in Fuyang of Zhejiang, Pingjiang of Hunan, and Muchuan of Sichuan.Table 1. Physical, chemical and biological properties of experimental soil (0-20 cm)

Surface runoff was affected by many factors including climatic, topographical, petrologic and land use. The factors such as precipitation, soil permeability, slope gradient and length, as well as land cover were considered the most important in controlling the surface runoff generation [19]. At a specific site with similar conditions of topography and pedology, vegetation plays a dominant role in reducing surface runoff. The species composition, vegetation type and spatial pattern are the crucial factors controlling the water holding capacity of soil at a specific site [20] The shrub and herbage are denser, and the litter layer is thicker in SB than in other vegetation types, which prevents surface runoff from generating in a short time after precipitation and slow runoff flow when the surface runoff has generated[21-22]. Soil permeability is higher in SB than in other vegetation types, resulting in a large portion of subsurface and interflow and reducing surface runoff in SB[23-25] These advantages lead to a lowest annual runoff flow and runoff coefficient in SB. Although the canopy density and trees density was higher in EF and EB, the annual runoff flow and surface runoff coefficient were pretty high. The spatial structure of EF and EB was made simple due to extensive managements, and the ample solar radiation accelerates decomposition of forest litter, reducing the water holding capacity in these forests. The herb and shrub layer and litter layer are usually mostly removed in farmlands, which produces more bare land. Furthermore, the soil is covered by the crops only in growing seasons. All these factors contribute to its limited ability to retain precipitation in farmlands.

3.2 Soil loss related to land use types

Table 1 shows the soil loss of the different land use/vegetation types in the east (Fuyang), central (Pingjiang) and west (Muchuan) area in subtropical China. The analysis indicates that the soil loss was significantly different among the land use/ vegetation types. The highest soil loss was found in the farmland, followed by economic forests, intensively managed bamboo forests and extensively managed bamboo forests, then by conifer forests and the lowest in secondary broadleaved forests. The soil loss of the farmlands was 3-9 times of that of the secondary broadleaved forests. All these data indicate that the forests have higher capacity to resist soil erosion than the farmland.

Soil erosion is the consequence of interaction between soil and its environment. The influential factors, including the resistance to erosion, erosion force, slope angle and length, land use /

vegetation type etc., vary substantially from site to site[19]. Land use /vegetation type regulates reallocation of precipitation and soil permeability and therefore affects sediment production processes driven by precipitation and runoff water. In the secondary broadleaved forests with less human disturbance, the vertical canopy layer of trees, shrubs and herbs increase the spatial structure heterogeneity, more precipitation will be retained by forest canopy and return to air as vapor [26-27]. Furthermore, the forest litter layer is also thick, holding more water and increasing soil permeability. All these factors contribute to high soil surface roughness and resistance to erosion[28-29]. In coniferous plantation, extensively managed bamboo plantation, intensively managed bamboo plantation and economic forest with more management, the canopy spatial structure heterogeneity is decreased and the litter layer is also less thick due to fast decomposition with more solar radiation, which can explain their higher soil loss than that of the secondary broadleaved forests. In farmland with highest soil loss, the vegetation cover is sparse and relatively homogenous. Therefore soil surface roughness and soil resistance to erosion are both decreased and consequently sediment production in precipitation processes and the capacity of the surface runoff water to carry sand are both increased which leads to much soil erosion[30-31].

Table 1 Annual soil loss ($kg.hm^{-2}.yr^{-1}$) of six land use types in three sites

Site	Land use type					
	BL	CF	EB	IB	EF	FL
Fuyang	1518.5	3091.5	6276.5	9646.0	9328.0	13621.0
Pingjiang	4617.5	9250.0	15680.5	19800.0	22500.0	29962.0
Muchuan	4588.0	7617.0	12366.0	N/A	19768.0	22821.0

3.3. RUNOFF WATER AND SOIL LOSS ALONG EAST-WEST GRADIENT

Table 1 shows the soil loss of the different land use/vegetation types in the east (Fuyang), central (Pingjiang) and west (Muchuan) area in subtropical China. The analysis indicates that the soil loss was significantly different among the land use/ vegetation types. The highest soil loss was found in the farmland, followed by economic forests, intensively managed bamboo forests and extensively managed bamboo forests, then by conifer forests and the lowest in secondary broadleaved forests. The soil loss of the farmlands was 3-9 times of that of the secondary broadleaved forests. All these data indicate that the forests have higher capacity to resist soil erosion than the farmland.

4. CONCLUSION

There was significant difference in surface runoff and runoff coefficient among the land use types. The surface runoff and runoff coefficient of FL ranked the highest, followed by EB, then CF, IB and EF, with BL as the lowest. The surface runoff and runoff coefficient of FL was about 2-7 times of that of

BL. There were similar effects of land use type on the soil loss. The BL had the lowest soil loss, followed by CF, EB, IB and the highest in FL. The characteristics of soil erosion from different land use types in the gradient from east to west differed significantly. The surface runoff coefficient and soil loss of the east was significantly lower than that of the west, which may be attributed to the different natural conditions, social and economical development stage and resources investment into soil and water protection.

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