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Comparison of Water and Soil Conservation Effect of Trees, Shrubs and Grasses in the Red Soil Area of Southern China

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Abstract Assessing the effects of vegetation on water and soil conversation is the key basis for research and management of ecological restoration on water-eroded areas. In this study, the runoff depth, soil loss and corresponding precipitation of five plots planted respectively with *Pueraria lobata*, *Lespedeza bicolor* Turcz, *Manglietia yuyuanensis* Law, *Paspalum natatu* Fliigge, *Paspalum wettsteinii* Hackel and one control plot were observed monthly from 2003 to 2010 in Hetian Town of Changting County, Fujian Province, a typical water-eroded area in southern China. Then the effects of different vegetation on water/soil conversation (RE/SE) were determined using the ratios of runoff depth/soil loss between vegetated plots to the control plot. Meanwhile, the effect of precipitation on the water and soil loss was also analyzed. The results showed that, both the water and soil conservation effects of *Pueraria lobata* and *Manglietia yuyuanensis* Law are better than *Lespedeza bicolor* Turcz and *Paspalum natatu*, while *Paspalum wettsteinii* Hackel are the worst. The differences of effects of water conservation are more significantly than those of soil conversation between five kinds of vegetations. The runoff depth is mainly affected by precipitation, the determination coefficients (R^2) of linear regression models between precipitation and runoff depth of all planted plots are all greater than 0.9, whereas the determination coefficients of the linear regression models between precipitation and soil loss vary form 0.3 to 0.8 for different vegetated plots. These results provide a reference for vegetation reconstruction in the current and similar areas.

Key words Effect, Vegetation type, Runoff, Soil erosion, Multiple comparison

1 Introduction

Due to natural conditions and historical reasons, the red soil erosion areas in southern China have become the serious soil erosion areas second only to the Loess Plateau[1], posing a direct threat to the health of the regional ecological environment, and to a large extent hindering the regional socio-economic development. Vegetation is a key factor for controlling soil erosion[2-3], so vegetation restoration and reconstruction is a common means to control soil erosion[4]. Over the years, the revegetation work in the southern water erosion areas has been widely carried out[5-6]. Then how is the water and soil conservation effect of different types of vegetation? It is an unavoidable question in the water and soil conservation work. Therefore, researching the water and soil conservation effect of vegetation is of urgent theoretical and practical significance. In recent years, the research of water and soil conservation effect of vegetation has been widely carried out. Yang Chunxia et al[7] researched the soil erosion differences of bare land, *Medicago sativa* Linn grassland and *Ligustrum quihoui* Carr. woodland, and the results showed that the role of grassland in reducing water and sand was the most significant, and affected by planting activities, the shrubbery planted not long had no the role of water and soil conservation, and the greater the planting density on the slope, the more serious the soil erosion. Zuo Changqing and Maliang[8] conducted research on three kinds of herbs (*Paspalum natatu* Fliigge, *Cynodon dactylon*, *Paspalum wettsteinii* Hackel), and the results showed that in terms of the vegetation's water conservation effect, *Paspalum natatu* Fliigge was the best, followed by *Cynodon dactylon*, and *Paspalum wettsteinii* Hackel was the poorest; at the same time, the greater the precipitation, the more obvious the differences in the water and soil conservation effect of vegetation. Fan Shuying and Wu Caijun[9] conducted comparative study of the water and soil conservation and soil improvement effect of *Pueraria lobata* and *Paspalum natatu* Fliigge on the red soil slope, and found that *Pueraria lobata* and *Paspalum natatu* Fliigge could effectively improve soil water holding capacity, improve soil pH value, increase soil organic matter and N, P, K content, and greatly reduce the amount of runoff and soil erosion, and the combined effect of *Pueraria lobata* was better than *Paspalum natatu* Fliigge. The studies of Wu Datong[10] showed that biennial *Lespedeza bicolor* Turcz could reduce 74.2% of soil erosion; if *Paspalum natatu* Fliigge was grown between the ditch, the erosion could be effectively controlled in the year. Chen Renxing and Wang Yi[11] conducted intercropping of *Lespedeza bicolor Turcz*, *Albizzia julibrissin Durazz*, *Robinia pseudoacacia*, *Acacia mearnsii de Wilde* in the *Pinus massoniana* forest land, and the observation results showed that the runoff coefficient of woodland intercropped with *Lespedeza bicolor* Turcz was 12.1% less than that of pure stand, 19.8% less than that of areas without growing trees; meanwhile, the soil loss was zero.

In conclusion, the researches on the water and soil conservation effect of different vegetation types have yielded fruitful results. However, many existing studies are mainly focused on single shrub or herbaceous vegetation, and the comparison of effect between different vegetation is rarely reported. Moreover resear-

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ches are mostly based on the absolute amount of the loss of runoff and soil erosion, and it is the result arising from the combined effects of various soil erosion factors, so there are some limitations in comparing the water and soil conservation effect of vegetation. Based on perennial arbor (*Manglietia yuyuanensis*), shrub (*Lespedeza bicolor* Turc), grass (*Pueraria lobata*, *Paspalum natatu* Fliigge, *Paspalum wettsteinii* Hackel), the runoff depth, soil erosion and the corresponding precipitation data in the control plots, this article calculates the monthly runoff depth ratio and soil erosion ratio between vegetated plots and control plots, as the water and soil conservation effect values, respectively. Using multiple comparison method, this article analyzes the differences in the water and soil conservation effect between different vegetated plots, and explores the relationship between the soil erosion and precipitation in different vegetated plots, in order to provide reference for the research and management of water and soil conservation.

2 Materials and methods

2.1 Description of the study plots The study plots are in Hetian Town, Changting County, Fujian Province (25°38′17.9″ N, 116°27′ 35.7″ E), one of the regions in Fujian Province with the most serious soil erosion. It has a subtropical monsoon climate, with the annual average temperature of 17 – 19 .5℃, the highest temperature of 39.8 ℃ and the minimum temperature of –4.6 ℃ in the history. The annual average precipitation is 1621 mm, but the seasonal distribution is very uneven. The precipitation from April to June may account for 50% of that of the whole year; the precipitation in July and August is mostly short afternoon rainstorm; the precipitation in January and October is the least. The landform is mainly the low mountains and hills, distributed in the edge of mountains and periphery of basin. The loss of topsoil easily happens in the slope under the forces of nature. The soil is the mountain red soil formed from weathering of granite. Under the effect of heavy rain-drought cycle during the year, the weathering is very strong, making the soil vulnerable to erosion. The zonal vegetation in this area is subtropical evergreen broad-leaved forest, and the main tree species are *Castanopsis eyrei*, *Quercus glauca*, *Lithocarpus* sp., and *Elaeocar chinensis*. However, due to the history of severe deforestation, the broadleaf forest has been destroyed, and the existing vegetation is mainly Pinus massoniana. The under-forest vegetation mainly includes *Lespedeza bicolor* Turcz, *Adinandra millettii*, *Dicranopteris dichotoma*, *Syzygium grijsii*, and *Vaccinium carlesii*. In the area with severe soil erosion, the land is almost bare, and the shrub and grass coverage is very low.

2.2 Establishment of plots In November 2002, 5 vegetated plots, and 1 bare land control plot (6 soil erosion experimental plots in total) were built at the same time. All plots are distributed in the northeast slope of Luhu Ecological Park in Hetian Town, and the interval between the plots is about 3m. The soil in the plots is the mountain red soil stemming from parent material of granite; the slope is even, with the gradient of 23°and the projection size is 5m × 20m. All plots set up the enclosed runoff pool to collect runoff and sediment. In the 5 vegetated plots, *Pueraria lobata*, *Lespedeza bicolor* Turcz, *Manglietia yuyuanensis* Law, *Paspalum natatu* Fliigge, and *Paspalum wettsteinii* Hackel, were planted in small horizontal ditch; the control plot is without vegetation cover (Fig. 1). The cover of each plot is almost similar among the observed years.

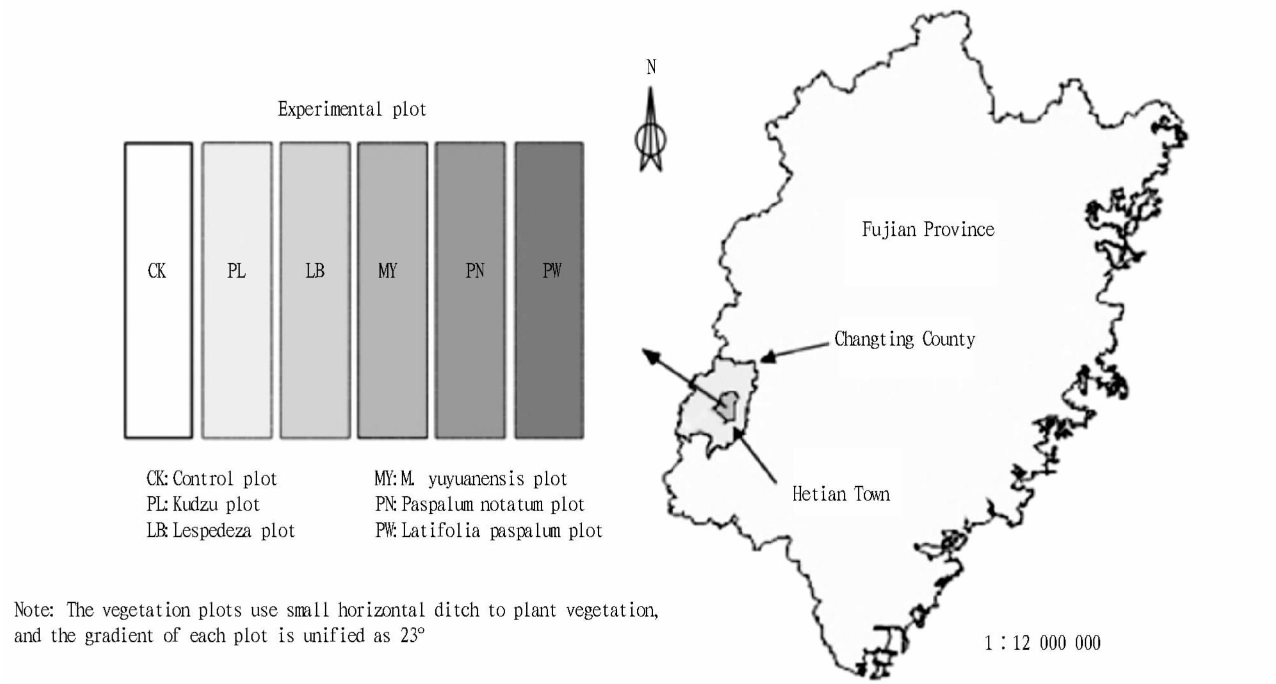
2.3 Plot observation and data analysis The experimental plots were observed once a month from January 2003, and the precipitation data were read from a rain meter curve. The data were from the meteorological observatory around the experimental plots. Using the runoff pond water level measured each time to multiply the pond bottom area, then divided by the projected area of the plots, we can get the runoff depth (RD/mm) in the plots arising from the previous precipitation. The sum of plot sand and suspended sediment measured using drying method was used as the monthly amount of soil erosion in the plots (SL/kg). The data on *Paspalum natatu* Fliigge and *Paspalum wettsteinii* Hackel plots in 2006 and 2009 were missing. Based on the definition of vegetated control and management factor C value in the USLE equation[12], we use the runoff depth ratio of vegetated plots and control plot to signify the water conservation effect (RE) of plot vegetation, and use the soil erosion ratio of vegetation plots and control plot in each month to signify the soil conservation effect (SE) of plot vegetation.

When comparing the water and soil conservation effect of different vegetation types, we use single-factor variance analysis to take vegetation types as factor variable, RE and SE as dependent variable, and choose Duncan multiple comparisons to test consistency subset[13]. When analyzing the relationship between precipitation and soil erosion, we collect the 7 years of statistics on precipitation, runoff depth and soil erosion by month, then take precipitation as independent variable, runoff depth or soil erosion as dependent variable, to establish single-variable linear relationship model between precipitation and runoff depth, between precipitation and soil erosion, respectively. The statistical and analysis work is completed using SPSS17.0 (SPSS Inc., USA).

3 Results and discussions

3.1 Water conservation effect The runoff depth (RD/mm) in the experimental areas in different years is shown in Fig. 2. Apart from the data on *Paspalum natatu* Fliigge and *Paspalum wettsteinii* Hackel unobserved in 2009, RD of the plots in the seven years is 6375.5 mm in total. There are great differences in the runoff depth between the plots. The runoff depth of control plot (1419.5 mm) in the seven years is higher than that of vegetated plots, and the runoff depth of *Manglietia yuyuanensis* plot (935.1 mm) and *Pueraria lobata* plot (904.7 mm) is the lowest. Runoff depth reflects the absolute amount of surface runoff in the plots, but due to the negative effects of vegetation water conservation[14] and the impact of precipitation, topography, soil and other background factors[15], there is uncertainty to use runoff depth to re-present the water conservation effect of vegetation. Water conservation ieffect value RE can to some extent eliminate the impact of background effects. The smaller the RE, the stronger the water conservation effect. We collect the statistics on RE mean and standard deviation of five vegetated plots in the seven years, and use Duncan method in single – factor variance analysis to conduct multiple comparison of RE values of different vegetation plots in the same year (Table 1). It can be seen from Table 1 that various vegetation plots show different water conservation effects. From the average RE in seven years, the vegetation type with the best water conservation effect is *Pueraria lobata* (0.63) and *Manglietia yuyuanensis* (0.66). On the one hand, the two have deep and developed roots which are conducive to loosening the soil, increasing the soil porosity and increasing water infiltration[8, 16]; on the other hand, the litter in a large amount has strong ability to store precipitation[17], and rainwater is easy to quickly infiltrate[18]. So the effect of the two reducing the surface runoff is better than that of other vegetation. The water conservation effect value of *Lespedeza bicolor* Turcz and *Paspalum natatu* Fliigge is 0.70 and 0.77, respectively, and the root and litter volume of the two types of vegetation are not as good as *Pueraria lobata* and *Manglietia yuyuanensis*, so the water conservation effect is a little bit poorer. RE of *Paspalum wettsteinii* Hackel is 0.94, and according to observation, *Paspalum wettsteinii* Hackel grows slowly and degenerates in the study plots, thereby showing the water conservation effect obviously different from other vegetation types.

Overall, the vegetation in various plots has played a role in water conservation to some extent, but there are significant differences in the water conservation effect between groups, namely *Pueraria lobata* and *Manglietia yuyuanensis* are the best, followed by *Lespedeza bicolor* Turcz and *Paspalum natatu* Fliigge, and *Paspalum wettsteinii* Hackel is the poorest.



Note: The vegetation plots use small horizontal ditch to plant vegetation, and the gradient of each plot is unified as 23°

Fig. 1 The location of the study area and plot distribution map

3.2 Soil conservation effect The monthly soil loss (SL/kg) in the experimental areas over the years is shown in Fig. 3. The soil loss in all plots was 6375.5 kg from 2003 to 2010, and there are significant differences in the soil loss between vegetated plots. The total amount of the control plot (578.5 kg) and *Paspalum wettsteinii* Hackel plot (578 kg) in the seven years is significantly higher than that of other plots, followed by *Lespedeza bicolor* Turcz (370.1 kg); the amount of *Manglietia yuyuanensis* plot, *Paspalum natatu* Fliigge plot and *Pueraria lobata* plot is low, with the proportion close to 13%. Similar to the water conservation effect, soil conservation effect value SE can eliminate the negative effects of soil conservation of vegetation[19–20], and the impact of background factors[15]. The smaller the SE, the better the soil conservation effect. From the data analysis (Table 1), except the *Paspalum wettsteinii* Hackel plot, all plots have played a role in reducing sediment yield on the whole, and the ranking of vegetation in terms of soil conservation effect is consistent with that of vegetation in terms of water conservation effect. The vegetation with the best soil conservation effect is *Pueraria lobata* (0.62) and *Manglietia yuyuanensis* (0.70). Their well – developed roots and a lot of litter can well reduce the effects of runoff on surface[9, 16, 17] and enhance the soil's water permeability[21]. It is followed by the soil conservation effect of *Lespedeza bicolor* Turcz (0.71) and *Paspalum natatu* Fliigge (0.85). There are no significant differences among *Pueraria lobata*, *Manglietia yuyuanensis*, *Lespedeza bicolor* Turcz and *Paspalum natatu* Fliigge. Due to degradation, the soil conservation effect of *Paspalum wettsteinii* Hackel (1.47) is the worst, and there is negative effect of soil conservation, so it is significantly different from other vegetation. The above analysis shows that the difference in the soil conservation effect between different types of vegetation is not as obvious as the water conservation effect. In addition, except the soil conservation effect value of *Paspalum wettsteinii* Hackel significantly higher than water conservation effect value, the soil conservation effect of other vegetation types is close to the water conservation effect.

Table 1 The water and soil conservation effect (RE/SE) of various vegetated plots and multiple comparison results

Effect types	Vegetation types				
	Pueraria lobata	Lespedeza bicolor Turcz	Manglietia yuyuanensis	Paspalum natatu Fliigge	Paspalum wettsteinii Hackel
Water conservation effect	0.63 ±0.24a	0.70 ±0.21ab	0.66 ±0.37a	0.77 ±0.39ab	0.94 ±0.32c
Soil conservation effect	0.62 ±0.39a	0.71 ±0.45a	0.70 ±0.64a	0.85 ±0.79a	1.47 ±1.06b

Note: The data in the table are mean ± standard deviation, and the letter different from other letters in the same line shows that it reaches significant difference ($p < 0.05$).

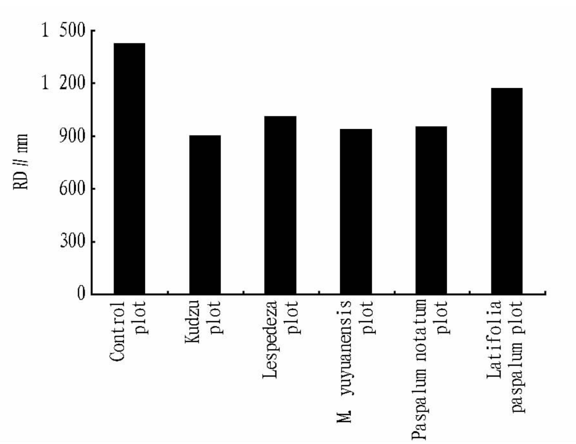


Fig. 2 The sum of runoff depth in experimental plots over the years

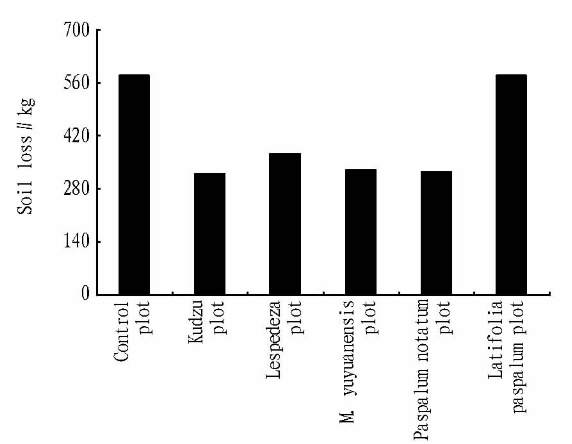


Fig. 3 The sum of soil loss in the experimental plots over the years

3.3 The relationship between soil loss and precipitation

From 2003 to 2010 (except 2006), the annual and monthly average precipitation was 1376.6 m and 114.7 mm, respectively. The precipitation was the highest in 2010 (1709.0 mm), and lowest in 2003 (996.0 mm) (Fig. 4a). There were small differences in the precipitation between the years, and the variance coefficient is 0.191. On the whole, the precipitation shows a growth trend. It continued to grow in the period 2003 – 2007, and experienced a turning point in 2008, but continued to grow in the rest two years. The precipitation in the experimental areas is mainly concentrated in March to August (Fig. 4b), accounting for 81.5% of total precipitation. June is the month with the most concentrated precipitation, accounting for 22.8% of total precipitation. There are significant differences in the precipitation between the months, and the variance coefficient is 0.823. Due to significant difference in the precipitation between months, so we choose the monthly scale to analyze the relationship between soil loss and precipitation. We establish the single – variance linear relationship model between soil loss and precipitation, as is shown in Table 2. The coefficient of determination (R^2) and significance level (Sig.) are generally high. The equation gradient is positive, showing the positive correlation between soil loss and precipitation. The determination coefficient of determination between runoff depth and precipitation in different vegetated plots is in 0.896 (*Manglietia yuyuanensis*) and 0.925 (*Paspalum natatu* Fliigge). The coefficient of determination between soil loss and precipitation in different vegetated plots is relatively low. Except the control plot (0.802) and *Paspalum wettsteinii* Hackel plot (0.742) with high coefficient of determination, other plots have the coefficient of determination in 0.357 (*Pueraria lobata*) to 0.581 (*Paspalum natatu* Fliigge). From the above analysis, it shows that the precipitation has more obvious impact on runoff depth than on soil erosion, and the poorer the soil conservation effect of vegetation, the closer the relationship between soil loss and precipitation of vegetated plots.

In the process of researching the relationship between soil loss and precipitation, this article also uses the water and soil conservation effect value (RE/SE) to replace the absolute value of water/soil loss (RD/SL) to establish equation, but the equation is fitted poorly ($R^2 < 0.2$, $P < 0.1$). We can see that the water and soil conservation effect value is not suitable for the analysis of the relationship between soil loss and precipitation, because the effect value eliminates the background factors including precipitation and highlights the impact of vegetation on water and soil conservation.

4 Conclusions

Based on the data concerning runoff depth, soil loss and corresponding precipitation of 6 experimental plots (*Pueraria lobata*, *Fliigge*, Paspalum wettsteinii *Hackel and control*) *in Hetian Town*,

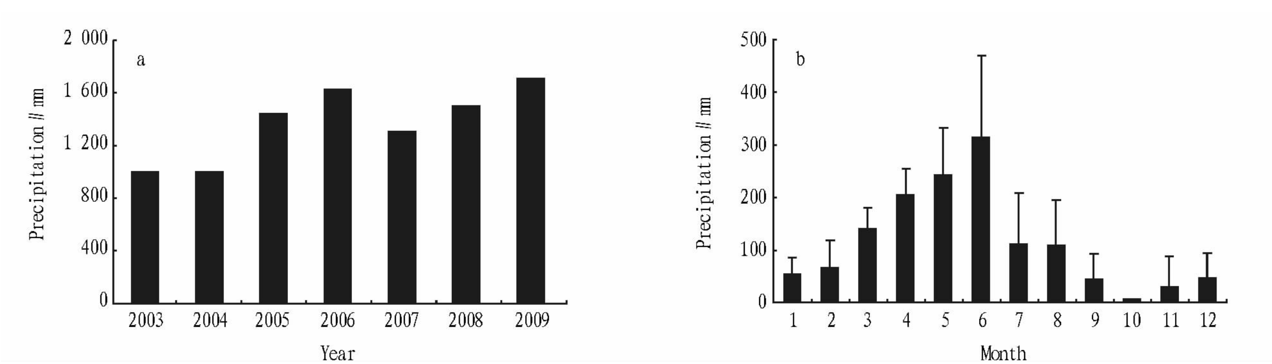


Fig. 4 The distribution of annual and monthly precipitation (a is the annual total annual precipitation and b is the mean ± standard deviation of monthly precipitation)

Table 2 The relationship between precipitation and soil loss (RD/SL) in different vegetated plots

Category	Plot	Equation	The coefficient of determination (R^2)	Significance level (Sig.)
Precipitation and runoff depth	Control	$y = 0.142x + 4.956$	0.919	0.000
	Pueraria lobata	$y = 0.092x + 1.744$	0.917	0.000
	Lespedeza bicolor Turcz	$y = 0.097x + 6.765$	0.912	0.000
	Manglietia yuyuanensis	$y = 0.094x + 2.848$	0.896	0.000
	Paspalum natatu Fliigge	$y = 0.102x - 2.119$	0.925	0.000
	Paspalum wettsteinii Hackel	$y = 0.126x - 3.650$	0.924	0.000
Precipitation and soil erosion amount	Control	$y = 0.053x + 5.902$	0.802	0.000
	Pueraria lobata	$y = 0.026x + 5.736$	0.342	0.040
	Lespedeza bicolor Turcz	$y = 0.027x + 9.508$	0.487	0.012
	Manglietia yuyuanensis	$y = 0.023x + 8.921$	0.493	0.011
	Paspalum natatu Fliigge	$y = 0.031x + 2.413$	0.581	0.004
	Paspalum wettsteinii Hackel	$y = 0.056x + 3.330$	0.742	0.000

Note: y is runoff depth (RD, mm) or soil loss (SL, kg), x is the precipitation (mm).

Changting County of Fujian Province during the period 2003 – 2010, this article analyzes the effects of water and soil conservation and precipitation on the soil erosion. The results show that, both the water and soil conservation effects of *Pueraria lobata* and *Manglietia yuyuanensis* Law are better than *Lespedeza bicolor* Turcz and *Paspalum natatu*, while *Paspalum wettsteinii* Hackel is the worst. The differences of effects of water conservation are more significantly than those of soil conversation between five kinds of vegetations. The runoff depth is mainly affected by precipitation, the determination coefficients (R^2) of linear regression models between precipitation and runoff depth of all vegetated plots are all greater than 0.9, whereas the determination coefficients of the linear regression models between precipitation and soil loss vary form 0.3 to 0.8 for different vegetated plots. These study results can provide a reference for the theoretical research and management decision-making of vegetation restoration and reconstruction in the red soil area of southern China.

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4 Conclusions

(1) In general, the average value of TN and SOC decreased with the increase of soil depth. In contrast, the average value of SWC showed as A1 < A2 < A3 < A4, which means the SWC content increases as the soil depth increases. The change of TP with soil depth was not obvious.

(2) Variable coefficients of TN, SWC, SOC and TP, all belonging to medium variations, were all between 0.10 and 1.00; and their Nugget coefficients were all smaller than 0.25 basically, indicating their strong spatial dependence.

(3) In four sampling depths, semi-variance model can simulate the precisions of TN, SWC and TP in A1 and A2 well. The spatial structure of SOC was poorer, which could not be simulated with semi-variance model well.

(4) The analysis with Kriging interpolation showed that, TN, SWC and TP were in layered distribution in A1 and A2; when the spatial structure changed to A2 from A1, the average TN content reduced to 0.310 g/kg from 0.598 g/kg, while the average SWC and TP content increased to 15.439% and 0.366 g/kg from 12.988% and 0.229 g/kg, respectively.

(5) With the increase of depth, the positive autocorrelation distance of TN got smaller from A1 to A2, while the positive autocorrelation distances of SWC and TP both increased.

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