https://doi.org/10.17221/147/2017-SWR

Water and sediment runoff and soil moisture response to grass cover in sloping citrus land, Southern China

Minghao Mo[1,2], Zhao Liu[1,2], Jie Yang[1,2], Yuejun Song[1,2], Anguo Tu[1,2], Kaitao Liao[1,2], Jie Zhang[1,2]*

[1]*Jinagxi Institute of Soil and Water Conservation, Nanchang, P.R. China*
[2]*Jiangxi Provincial Key Laboratory of Soil Erosion and Prevention, Nanchang, P.R. China*
**Corresponding author: zhaoliu1989@foxmail.com*

Citation: Mo M., Liu Z., Yang J., Song Y., Tu A., Liao K., Zhang J. (2019): Water and sediment runoff and soil moisture response to grass cover in sloping citrus land, Southern China. Soil & Water Res., 14: 10–21.

Abstract: Soil erosion is recognized as one of the major environmental problems in the hilly red soil region of Jiangxi province, southern China. An eight-year field experiment was conducted to evaluate the effects of grass cover in the sloping citrus land on water and sediment runoff. Soil moisture regimes were also analysed based on the *in-situ* soil moisture measurement. Four treatments were carried out in the runoff plot experiment: (1) no vegetation, bare land (BL); (2) conventional treatment, citrus without grass cover (CK); (3) citrus with strip planting of Bermuda grass (SP); (4) citrus with full cover of Bermuda grass (FC). Results showed that the annual runoff volumes were significantly ($P < 0.05$) reduced using SP (27.2 mm) and FC (33.0 mm) compared with CK (311.4 mm) and BL (456.7 mm) treatments. The SP and FC treatments significantly ($P < 0.05$) reduced the annual average sediment yield by as much as 99.38% to 99.67%, compared with CK treatment. Soil moisture variations at the four depths (0–10, 10–20, 20–30, and 30–40 cm) were consistent with the seasonal precipitation patterns. Within the soil profile, soil moisture content increased with depth. In 3 of the 4 depths, the soil moisture contents of SP (21.20–27.84 m^3/m^3, mean value) were the highest. Soil moisture contents of FC (14.92–26.30 m^3/m^3, mean value) were lower than in SP because of the water consumption by plant transpiration, but were still higher than those of CK (16.03–25.00 m^3/m^3, mean value). Based on Richards' equation numerical model, optimization tool and observed soil moisture data, actual evapotranspiration was calculated, and water balance analysis was carried out during drought and rain periods. The results indicated that planting grass in sloping citrus land can effectively reduce surface water runoff and soil erosion and increase water infiltration, but the risk of drought, resulting from planting grass, should be noticed. Compared with FC, the drought risk of SP was much lower during the drought period, and SP contributed to storage of more water in the root zone during the rain period. In conclusion, SP was a recommendable treatment.

Keywords: Richards' equation; red soil slope; soil and water conservation; soil moisture content

Use of hilly land to develop slope agriculture has become an inevitable trend, especially in the hilly red soil region of southern China where land resources are limited (Liang *et al*. 2010; Shi *et al*. 2012). However, rainfall induced runoff can cause severe soil erosion in the region due to inappropriate tillage practices and land cover, leading to soil degradation and water pollution (Basic *et al*. 2004; Kinnell 2005; Wilson *et al*. 2008; Curtis *et al*. 2009; Wang *et al*. 2010). It was reported that 46.2% of the soil loss came from cultivated slope land (Shi *et al*. 2009). Therefore, developing best management practices for conserving soil and water resources is critical to sustain agricultural production for the slope tillage.

Supported by the National Natural Science Foundation of China (41501300, 41761060 and 41601297), Natural Science Foundation of Jiangxi Province, China (20161BAB216148), Outstanding Talent Foundation of Jiangxi Province (20171BCB23080) and Project of Jiangxi Provincial Water Resources Bureau (KT201718, KT201420).

https://doi.org/10.17221/147/2017-SWR

Citrus is one of the main tree crops growing on the red soil slopes in southern China where the ecological conditions are favourable for both citrus quality and yield (Liu *et al.* 2012; Xia *et al.* 2015). However, development of the large-scale citrus industry has changed the original land use type and altered the vegetation composition in the region, which substantially affected the regional hydrological processes and the water cycle. Therefore, characterizing the hydrological processes and developing soil and water conservation management practices become an important research topic in the sloping orchard ecosystem.

Compared with the clean tillage method, vegetation management practices such as mulching and planting grass in the sloping citrus land can reduce soil and water runoff. A number of soil erosion studies indicated that erosion can be reduced below the allowable threshold values and soil properties can be greatly improved by selecting appropriate vegetation management practices, tillage methods, and/or land cover patterns (Lal 1989; Tucker *et al.* 1997; Agus *et al.* 1999; Cook 2000; Nigo-Mbogba *et al.* 2015; Roundy *et al.* 2017).

A six-year citrus field experiment in the Three Gorges Region of China showed that alley crop planting can significantly reduce water and soil sediment runoff (Wang *et al.* 2010). They found the water runoff and sediment runoff on crop planting land were 48.11% to 94.47% and 24.57% to 85.77%, respectively, those of the conventional tillage treatment. A study in the Danjiangkou Reservoir area of China also indicated that runoff volumes were significantly ($P < 0.05$) decreased using straw mulching compared with the conventional treatment and plastic film mulching in the citrus field, and the sediment yields were reduced by 18–22% (Liu *et al.* 2012). Another field trial on sloping citrus land showed that intercropping with *perennial white clover* could significantly reduce water and nutrient (N and P) losses (Xia *et al.* 2015).

In severely eroded hilly areas of South China, it is recommended to follow the land surface management model of *Paspalum notatum Flugge* or other grasses and horizontal interplantation of fruit trees and crops (Wang *et al.* 2011). In addition, except for water runoff and soil sediment runoff, the soil moisture regime is also an important hydrological factor (Western *et al.* 2004; Zheng *et al.* 2006; Gao *et al.* 2013; Liu & Shao 2014). The pattern of soil moisture dynamics on citrus sloping land under different cover also needs to be studied. In fact, the soil moisture regime of the upper part of the unsaturated zone is affected by many processes, e.g., infiltration, evapotranspiration, water exchange with deeper zone, etc., and a soil hydrodynamic model (e.g., Richards' equation) is often used to describe soil water movement (Harter & Hopmans 2004). For field-scale unsaturated water flow, the flux is usually very small in the horizontal direction, and one-dimensional Richards' equation was used for the sake of simplicity (Zhu & Mohanty 2002; Liu *et al.* 2016b). Thus, the water balance analysis and the numerical method to solve one-dimensional Richards' equation would help to analyse the soil moisture dynamics.

Few studies are available on characterizing water and sediment runoff and soil moisture under cover-crop management practices, especially in red soil slopes of China. In this study, we conducted a field plot runoff experiment with different land cover treatments to better understand water and soil runoff, and soil water regimes under the conditions of natural rainfall on the sloping citrus land aimed at selecting suitable citrus plantation methods.

MATERIAL AND METHODS

Area of study. The study area lies in the Jiangxi Provincial Eco-Science Park of Soil and Water Conservation (29°16'–29°17'N, 115°42'–115°43'E), which is located in De'an County, Jiangxi Province, China and belongs to the Boyang River watershed of the Poyang Lake Basin (Figure 1). This region is characterized by a subtropical humid monsoon climate with mean annual precipitation of 1397.3 mm. The average annual temperature is 16.7°C (the highest monthly temperature occurs in July up to about 40°C and the lowest in January), the annual sunshine hours are 1650~2100 h, the average annual frost-free period is 149 days (Liu *et al.* 2016a). The field soil is red soil (fine, kaolinitic, thermic, Udults), most of which exists in the hilly land. The status vegetation types are mainly natural secondary, semi-secondary and artificial trees and their associated shrubs and ground cover vegetation.

Experimental design and treatments. Four treatments of four runoff plots were studied: bare land (BL), citrus without grass cover (CK), citrus with Bermuda grass (*Cynodon dactylon*) strip planting (SP), citrus with Bermuda grass (*Cynodon dactylon*) full cover (FC) (Figure 1, Table 1). Each plot contained 12 citrus trees

https://doi.org/10.17221/147/2017-SWR

Figure 1. Location of the study area and experimental runoff plots
BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover

(Ponkan, *Citrus reticulata* Blanco) except BL, and the trees were planted in 6 rows (two trees in each row) with 2.5 m spacing (row spacing) × 3 m (line width). The field plots were established in 2000. The original physical properties of the soil for each treatment are shown in Table 2.

Four runoff plots with slopes of 12°, separated by concrete borders, were set up with three collecting tanks at the bottom of each plot to collect the water and sediment. Each runoff plot was 5 m wide by 20 m long, had concrete borders that extended 20 cm.

Rainfall data were automatically recorded by the meteorological observatory near the plots. The measurements included the water runoff and sediment yield after each rainfall. Soil moisture content in the profile was measured monthly for each plot by a soil moisture content tester that used Frequency Domain Reflectometry (FDR) technology (PR2-4, DELTA-T, Cambridge, UK). Probe tubes were buried in the uphill, middle and downhill slope of each plot and soil moisture contents of four different depths (0–10, 10–20, 20–30, and 30–40 cm) were measured. The meteorological observatory also provided other daily meteorological data, e.g., wind speed, air temperature, hours of sunshine, pressure, relative humidity, etc. Based on these data, reference evapotranspiration (ET_0), representing the water consumption capacity of the atmosphere, was calculated by a Penman-Monteith model (Allen *et al.* 1998).

Statistical analysis. Eight years' continuous water runoff and sediment yield data (2001–2008) were used and one full year's (2010) soil moisture test data were selected for analysis in this study. Experimental data were analysed using the SPSS 16.0 software (Ver. 16.0,

Table 1. General conditions of experimental runoff plots

Treatment	Description
BL	no vegetation
CK	clean tillage method (conventional treatment); removing weeds on the ground periodically; vegetation structure: fruit trees
SP	partial vegetation cover: horizontal strip cover with 1.0-m width and 1.10-m strip spacing, maximum vegetation coverage was 80%; vegetation structure: fruit trees-grass
FC	full vegetation cover: full cover with grass under the trees, maintaining vegetation coverage over 95%; vegetation structure: fruit trees-grass

BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover

https://doi.org/10.17221/147/2017-SWR

Table 2. Physical properties of the test soil

Physical properties		Treatment			
		BL	CK	SP	FC
Routine parameters	bulk density (g/cm^3)	1.36	1.34	1.34	1.32
	total porosity (%)	48.1	48.5	48.5	48.1
	clay (%)	30.1	26.5	29.7	29.9
	silt (%)	64.2	67.5	63.5	64.9
	sand (%)	5.8	6.0	6.9	5.2
Soil hydraulic parameters	θ_r (cm^3/cm^3)	0.086	0.083	0.086	0.087
	θ_s (cm^3/cm^3)	0.466	0.465	0.468	0.477
	α (1/cm)	0.0072	0.0064	0.0071	0.0072
	n (–)	1.55	1.59	1.55	1.55
	K_s (cm/day)	12.0	15.3	13.8	14.6

Soil hydraulic parameters were used to describe the van Genuchten-Mualem model (van Genuchten 1980); BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover; θ_r – residual soil water content; θ_s – saturated soil water content; α – reciprocal value of the air entry pressure; n – grain size distribution parameter; K_s – saturated hydraulic conductivity

2008). One-way analysis of variance (ANOVA) was carried out to determine differences between the treatments. Least significant difference (LSD) was used to elucidate any significant differences. One-dimensional Richards' equation was used to describe soil flow movement, and soil moisture was as its primary variable. Root mean square error (RMSE) was used to evaluate errors between simulated and observed soil moisture.

Water balance analysis. As shown in Figure 2, the soil profile was divided into two layers. The upper layer was from soil surface to 50-cm depth, and evapotranspiration was assumed to occur in this layer. Thus, the water balance equation of upper layer from the time t_0 to t_e was expressed as

$$\Delta V_{sum} = V_{sum}(t_e) - V_{sum}(t_0) = P - ET - R + Q \quad (1)$$

where:

P – precipitation (L)

R – runoff (L)

ET – evapotranspiration (L)

Q – flux into the upper layer from the lower one (L)

t_e – initial time of water balance analysis

t_0 – ending time of water balance analysis

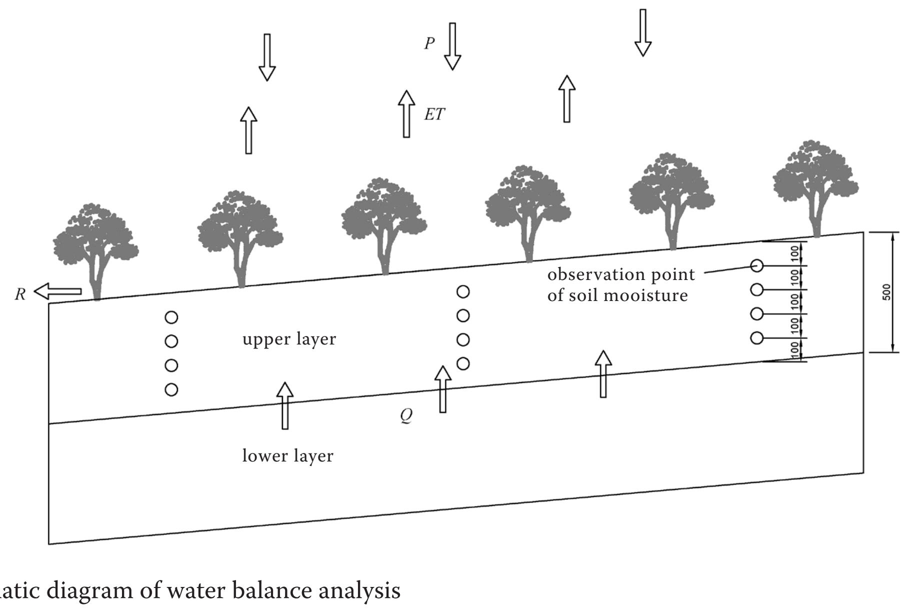

Figure 2. Schematic diagram of water balance analysis
The length unit is mm; P – precipitation; R – runoff; ET – evapotranspiration; Q – flux into the upper layer from the lower one

https://doi.org/10.17221/147/2017-SWR

V_{sum} – total soil water volume of the upper layer (L), i.e.,
ΔV_{sum} – difference of the total soil water volume of the upper layer between the end time and the initial time of the period

$$V_{sum}(t) = \sum_{i=1}^{4} \theta_{obs}(z_i, t)\Delta z_i \quad (2)$$

where:
z_i – depth of an observation point of soil moisture (z_1 = 10 cm, z_2 = 20 cm, z_3 = 30 cm, z_4 = 40 cm)
Δz_i – length of the cell i ($\Delta z_1 = \Delta z_4$ = 15 cm, $\Delta z_2 = \Delta z_3$ = 10 cm)
$\theta_{obs}(z_i, t)$ – arithmetic mean value of observed values of soil moisture at the same depth

Evapotranspiration evaluation. The relationship between *ET* (actual evapotranspiration) and ET_0 was assumed as follows:

$$ET = a\sum_{i=1}^{n} ET_0(t_i)\Delta t_i \quad (3)$$

where:
a – parameter that was related to treatments and vegetation period
t_1 – initial time
t_n – end time
Δt_i – time interval between t_i and t_{i-1}

According to our observations, most of soil moisture data were collected with nearly half-month interval, but daily soil moisture test data were recorded from July 15th to August 15th in 2010. Due to no rain from July 16th to August 6th, *ET* (or parameter *a*) during this period was inversed by a soil flow movement model. The mathematical model for the soil flow based on Richards' equation was written as

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[D(\theta)\frac{\partial\theta}{\partial z} - K(\theta)\right] \quad (4)$$

with upper boundary condition

$$D(\theta)\frac{\partial\theta}{\partial z} - K(\theta) = -ET \quad (5)$$

lower boundary condition

$$\theta(z_b, t) = \theta_{obs}(z_b, t) \quad (6)$$

and initial boundary condition

$$\theta(z, 0) = \theta_{obs}(z, 0) \quad (7)$$

where:
θ – simulated soil moisture
z – vertical elevation measured positive downward

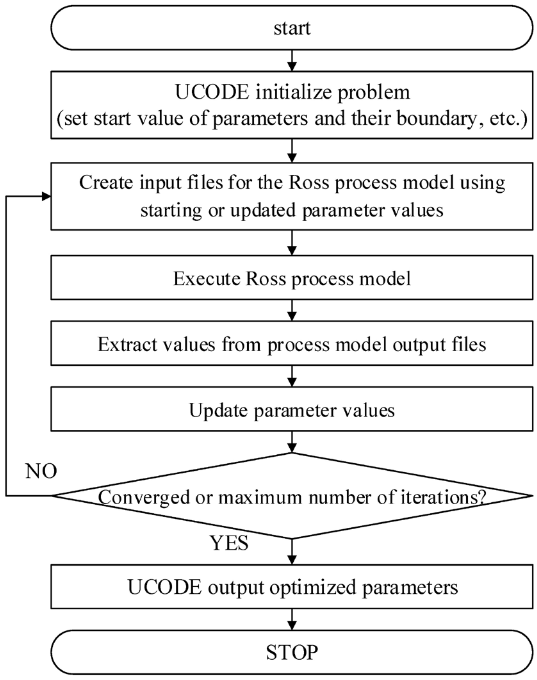

Figure 3. Diagram of evaluating evapotranspiration

x_b – location of lower boundary (x_b = 0.4 m in this case)
t – time
$D(\theta)$, $K(\theta)$ – hydraulic diffusivity (L/T^2) and conductivity (L/T), which were functions of θ

The relationships could be described by the van Genuchten-Mualem model (van Genuchten 1980), where the initial value of parameters could be evaluated by a pedotransfer function (ROSETTA software, Schaap *et al.* 2001).

Owing to higher efficient and better numerical stability (Zha *et al.* 2013), the Ross non-iterative numerical method (Ross 2003) was used to solve Eqs. (4)~(7) as a forward process model. Universal Inverse Code (UCODE, Poeter & Hill 1998) using a gradient-type minimization method provided users with flexibility in estimating parameters of forward models, so it was used to inverse *ET* (or parameter *a*). Figure 3 shows how to combine UCODE and Ross forward simulation to optimize *ET*.

RESULTS AND DISCUSSION

Rainfall and ET_0 pattern

In general, rain water in the study area was abundant and distribution of rainfall during a year was uneven. Its characteristic curve was bimodal (Figure 4). The first peak of rainfall was in April and the

https://doi.org/10.17221/147/2017-SWR

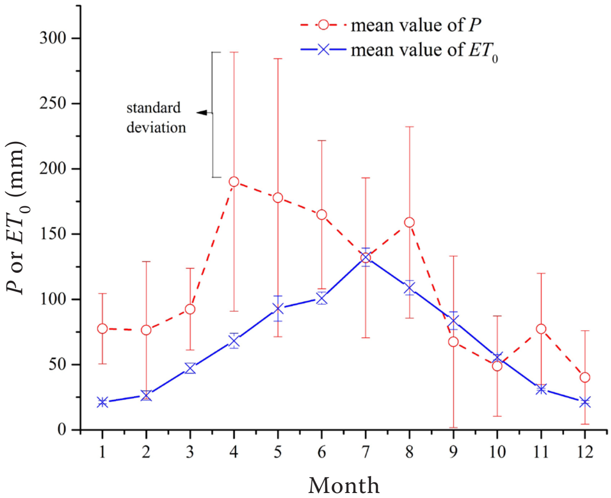

Figure 4. Average annual distribution of rainfall (P) and reference evapotranspiration (ET_0) in the study region from 2001 to 2008

second peak was in August. Rainfall from September to January of the following year was reduced significantly. The rainfall was mainly concentrated from April to August, and the average total rainfall in the five months from 2001 to 2008 accounted for 63.2% of the total annual rainfall. Rainfall also showed obvious uncertainty, and its coefficient of variation, i.e., the ratio of standard deviation to mean value, could reach 1.0. The coefficient of variation of ET_0 was significantly lower than that of rainfall, and the annual reference evapotranspiration (ET_0) was 790.0 mm, accounting for 60.6% of the total annual rainfall. The value of ET_0 during a year was also uneven, and it was mainly concentrated in the summer season (from May to September). Thus, the uneven and uncertain distributions of both rainfall and evapotranspiration often lead to frequent floods in rainy season and drought in dry season, which can adversely affect agricultural production.

Effects of grass cover on annual water and sediment runoff

Effects on water runoff. The effects of water runoff reduction in the citrus land were analysed using the observation data (Table 3) from treatments BL, SP, FC and CK from 2001 to 2008. The 8-year accumulative water runoff volume and annual water runoff in SP treatment were the lowest among the 4 treatments. The annual average runoff depth of SP was 27.2 mm, which was only 5.95% of that of BL treatment. Both the SP and FC treatments significantly ($P < 0.05$, LSD) reduced the water runoff. Compared with CK, the water runoff reduction in SP was 91.28% and in FC it was 89.39%. This was mainly because the use of cross-slope grass planting measures increased land cover and reduced a direct rainfall impact on soil, and improved soil infiltration capacity. As a result the surface runoff volume was reduced.

The maximum monthly runoff volume occurred in April in both SP and FC treatments, which was consistent with the time of the maximum rainfall. But the maximum monthly runoff volume in CK occurred in May and in BL it occurred in August. As it is shown in Figure 5, water runoff occurred mainly during the raining season from April to September. The runoff volumes of SP and FC in this half-year period accounted for more than 70% of the annual runoff and those of CK and BL accounted for 85% and 90%, respectively, of the annual water runoff.

The significantly lower runoff volume in the grass planting treatments during the raining season indicated that adopting the best management practices such as grass planting can effectively reduce water runoff and increase water storage in the soil during the period from April to September in sloping citrus lands, which is critical to combat periodic drought in the region.

Table 3. Characteristics of water and sediment runoff on different treatment plots from 2001 to 2008

Treatment	8-year cumulative water runoff (m^3)	Annual average water runoff depth (mm)	Water runoff reduction rate (%)	8-year cumulative sediment runoff (kg)	Annual sediment yield (t/ha/a)	Sediment reduction rate (%)
BL	365.36	456.7 ± 6.7^a	–	5012.40	62.65 ± 1.15^a	–
CK	249.13	311.4 ± 7.6^a	–	2168.61	27.11 ± 1.08^a	–
SP	21.74	27.2 ± 0.4^b	91.28	8.13	0.10 ± 0.003^b	99.63
FC	26.43	33.0 ± 0.4^b	89.39	13.37	0.17 ± 0.005^b	99.38

Values are given as means ± standard error of the mean (n = 8); values followed by different letters within a column are significantly different ($P < 0.05$); BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover

https://doi.org/10.17221/147/2017-SWR

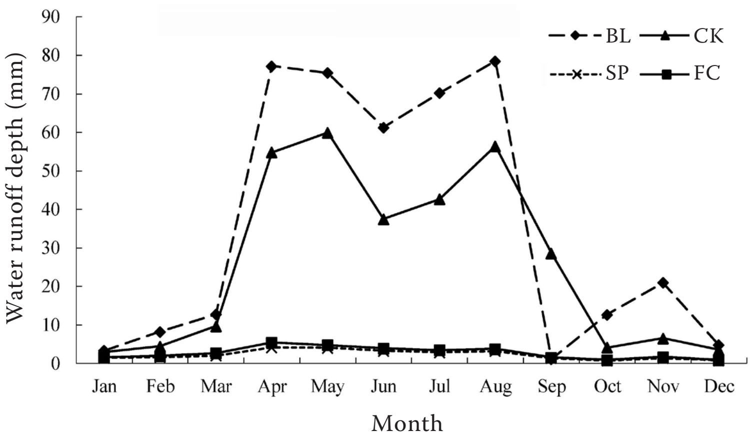

Figure 5. Monthly average runoff volume of different treatment plots from 2001 to 2008
BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover

Effects on sediment runoff. The sediment reduction rate was calculated and used to reflect the effect of grass planting on sediment yield. As shown in Table 3, the amount of sediment runoff in SP and FC plots was very small (only 0.2–0.3% of that of BL treatment), while under natural conditions soil erosion in the region was very severe when the slope was bare. The total amount of sediment runoff and the annual sediment yield in the CK plot was as high as 2168.61 kg and 2711 t/(km^2/a), respectively.

Compared with CK, the sediment reduction rate of SP and FC was 99.63% and 99.38%, respectively. For the 8-year sediment yield data, the single-factor analysis of variance showed that there were significant differences between the SP and CK treatments, and the FC and CK treatments (P < 0.05, LSD). The results of the analysis of variance also showed that the sediment reduction by Bermudagrass planting (SP and FC) was obviously better than that of BL and CK, but there was no significant difference between SP and FC. Thus the use of vegetation management practice could effectively reduce soil erosion in sloping land orchards, because the vegetation cover could reduce a raindrop impact on soil surface and reduce soil particles being carried to runoff.

Effects of grass cover on soil moisture regimes in sloping citrus land

Dynamics of soil moisture in CK. Seasonal variations of rainfall, temperature, light intensity and evapotranspiration rate can cause changes in soil moisture. Figure 6 shows the seasonal soil volumetric water content change in 0–10, 10–20, 20–30, and 30–40 cm soil layers in the CK plot (citrus land without grass cover) from January to December.

The trend of soil moisture content change at the four depths was consistent with the precipitation pattern. As the rainy season started, soil moisture content increased and it was relatively stable at a higher level before June, especially from April to June. From July to September, with the decrease of rainfall frequency and warmer temperature, both evaporation from the soil surface and transpiration by plants were very

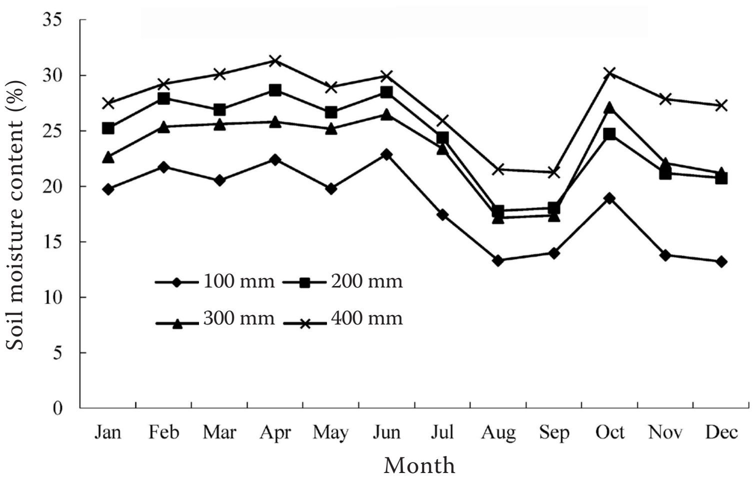

Figure 6. Soil moisture content of CK plot (citrus without grass cover) at different depths in 2010

https://doi.org/10.17221/147/2017-SWR

Table 4. Summary statistics of soil moisture contents in citrus land at different depths

Layer (cm)	Mean	Maximum	Minimum	CV (%)
	(m^3/m^3)			
0–10	16.03 ± 0.25	25.60	11.34	24.64
10–20	21.75 ± 0.20	30.07	16.46	19.64
20–30	21.05 ± 0.19	28.44	15.75	19.22
30–40	25.00 ± 0.14	32.13	19.91	14.15

Values are given as mean ± standard error (n = 57); CV – coefficient of variation

large, resulting in a soil moisture content decrease to a relatively stable but low level. From October, the soil water content increased due to the decrease in evapotranspiration. Although November and December were dry, soil moisture content decreased only slightly and it was still higher than that in July to September, except for the 0–10cm depth.

As shown in Figure 6 and Table 4, the soil moisture content of the citrus soil increased with the soil depth, but it was not significantly different between 10–20 and 20–30 cm depths. The soil moisture content at the 10–20 cm depth was often higher than that of the 20–30 cm depth, which can be attributed to two factors: more water uptake and less water holding capacity at the 20–30 cm depth. As expected, soil moisture content varied most at the 0–10 cm depth with a CV (coefficient of variation) of 24.64%, and least at the 30–40 cm depth (with a CV of 14.15%).

Effects of grass cover on soil moisture regimes. Comparing all the vegetation treatments with the bare soil treatment (Table 5), it was found that the average soil moisture content of SP was the highest at the 0–10 cm depth, while soil moisture content of BL was the highest in other layers among the four treatments. Among the three vegetation treatments, SP had the highest soil moisture content at all depths. The reason for higher soil moisture content in the deep layer might be related to that there was a low moisture uptake by plant roots there. The lowest CV for soil moisture content in BL (< 15%) also reflected that soil moisture content was relatively stable.

In all the four soil layers, the soil moisture content of SP was higher than that of CK, indicating that strip planting of grasses in the orchard had a good effect on water infiltration and water retention. Meanwhile, in all layers the soil moisture content of SP was 42% higher than that of FC at the 10 cm depth. However, the soil moisture content of FC was lower than that of CK, except for the 30–40 cm depth because the full coverage of Bermudagrass consumed more water in the shallow layers.

Figure 7 shows the soil moisture contents at different depths under different treatments in June, August, October, and December (representing dry, normal and wet season, respectively). At the 0–10-cm depth, the soil moisture contents were 20–30 m^3/m^3 in June and 17–24 m^3/m^3 in October during the wet seasons, 11–19 m^3/m^3 in August during the dry season, and 13–20 m^3/m^3 in December during the normal season. In August (dry season) when the soil moisture content was lowest, higher water storage in SP was more obvious. The annual mean soil moisture content at the 0–10 cm depth of CK was 13.3 m^3/m^3 and that of SP was 17.2 m^3/m^3. The latter was 29% higher than that of CK treatment. It indicates that grass planting

Table 5. Mean (in m^3/m^3) and coefficient of variation (CV, %) of soil moisture content in citrus land at different depths in the four treatments

Treatment		Depth (cm) 0–10	10–20	20–30	30–40
BL	mean	20.07 ± 0.39	26.05 ± 0.39	25.17 ± 0.35	33.28 ± 0.26
	CV	14.52	11.27	10.50	5.83
CK	mean	16.03 ± 0.25	21.75 ± 0.20	21.05 ± 0.19	25.00 ± 0.14
	CV	24.64	19.64	19.22	14.15
SP	mean	21.20 ± 0.62	22.50 ± 0.46	24.67 ± 0.39	27.84 ± 0.34
	CV	22.04	15.58	11.98	9.19
FC	mean	14.92 ± 0.55	15.80 ± 0.45	18.05 ± 0.61	26.30 ± 0.43
	CV	27.68	21.55	25.39	12.37

Values are given as mean ± standard error (n = 57); BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover

https://doi.org/10.17221/147/2017-SWR

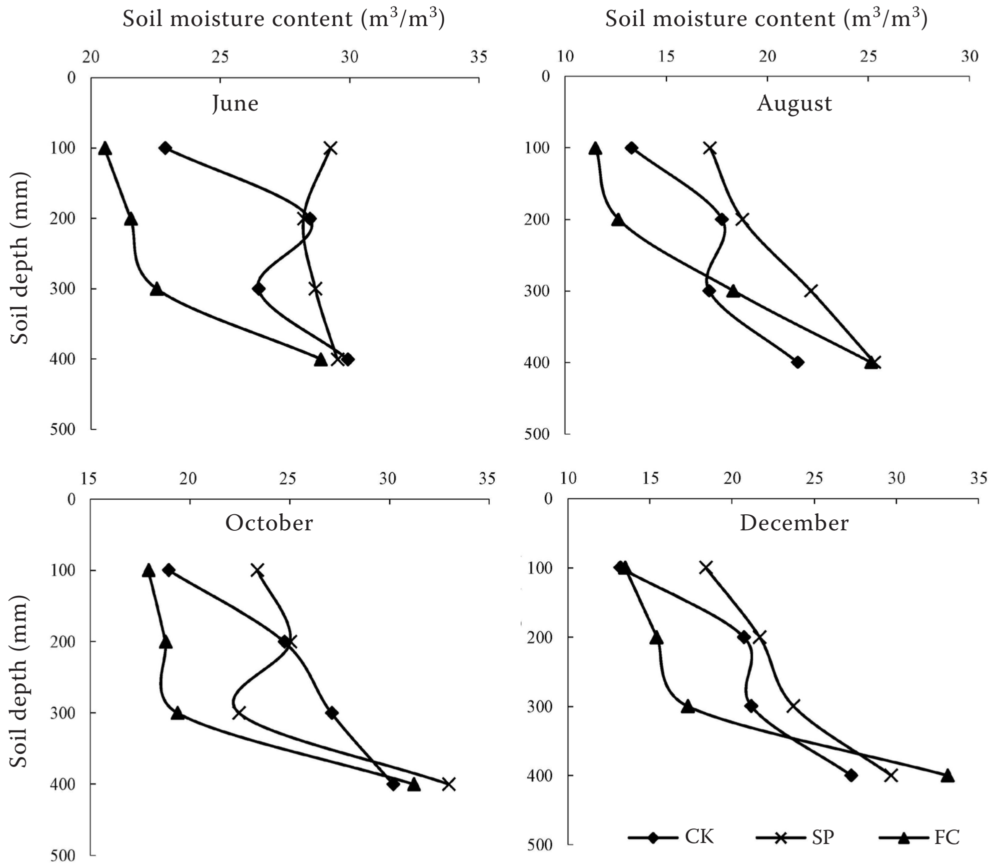

Figure 7. Soil moisture content distribution in the profiles under different treatments in selected months
CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover

is a good management practice for soil and water conservation in the dry season, which can minimize a seasonal drought impact on the crop yield.

Comparison between the soil moisture contents in June (high) and in August (low) showed that the amplitude of soil moisture variation in each treatment decreased with the depth. At the 20–30 and 30–40 cm depths, the respective soil moisture contents of CK in June were 54% and 39% higher than those in the two layers in August; in SP the respective amplitudes of variation were 29% and 16% between June and August; and in FC they were 22% and 15%. Based on the above analysis, grass planting was found to have a greater effect on water conservation in the shallow soil layer, and strip planting was better than that of full cover with grasses.

Water balance analysis during given periods. As mentioned above, there was no rain from July 16th to August 6th in 2010, and daily soil moisture data were collected during the drought period. Based on a combination of UCODE and Ross forward simulation, actual evapotranspiration (*ET*) was evaluated. As shown in Table 6, *RMSE*s between simulated value of soil moisture and observed value were less than 0.03, which indicated that the inversed *ET* had a high accuracy. The result also showed that ET_d (the subscript *d* represented the total value of the

Table 6. Results of real evapotranspiration evaluation

Treatment	Vegetation coverage (%)	ET_d (mm)	$a = ET_d/ET_{0,d}$	RMSE
FC	100	101.2	1.05	0.026
SP	60	79.8	0.83	0.018
CK	20	66.3	0.69	0.019
BL	0	28.6	0.30	0.025

BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover; ET_d and $ET_{0,d}$ are total actual evapotranspiration and reference evapotranspiration of the drought period, respectively; RMSE – root mean square error between simulated and observed soil moisture

https://doi.org/10.17221/147/2017-SWR

Table 7. Water balance analysis during the drought period

Treatment	Vegetation coverage (%)	P_d	R_d	ET_d	$\Delta V_{\text{sum},d}$	Q_d
		(mm)				
FC	100	0.0	0.0	101.2	–57.0	44.2
SP	60	0.0	0.0	79.8	–44.5	35.4
CK	20	0.0	0.0	66.3	–43.4	22.9
BL	0	0.0	0.0	28.6	–26.5	2.0

BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover; d – total value of the drought period; P – precipitation; R – runoff; ET – evapotranspiration; Q – flux into the upper layer from the lower one; ΔV_{sum} – difference in the total soil water volume of the upper layer between the end time and the initial time of the period

Table 8. Water balance analysis during the rain period

Treatment	Vegetation coverage (%)	P_r	R_r	ET_r	$\Delta V_{\text{sum},r}$	Q_r
		(mm)				
FC	100	66.1	0.6	39.7	19.8	–6.0
SP	60	66.1	0.6	31.3	21.2	–13.0
CK	20	66.1	8.2	26.0	9.4	–22.5
BL	0	66.1	14.7	11.2	10.6	–29.6

BL – bare land; CK – citrus without grass cover; SP – citrus with Bermudagrass strip planting; FC – citrus with Bermudagrass full cover; r – total value of the rain period; P – precipitation; R – runoff; ET – evapotranspiration; Q – flux into the upper layer from the lower one; ΔV_{sum} – difference in the total soil water volume of the upper layer between the end time and the initial time of the period

drought period, similarly hereinafter) increased with the increase of vegetation coverage.

According to Eqs. (6) and (7), water budget of two layers of the soil profile is shown in Table 7. All values of $\Delta V_{\text{sum},d}$ were negative, and all values of Q_d were positive, which showed that the total soil water volume of both layers was consumed. In the drought period, larger vegetation coverage would result in larger soil water consumption, but the upper layer consumption of SP was slightly higher (2.5%) than that of CK, while that of FC was 31% higher than that of CK. The ratios of Q_d of SP and FC to that of FC reached 1.9 and 1.5, respectively. In short, the risk of drought of SP would be close to that of CK which was much lower than that of FC.

There were 5 rainfall events from August 16$^{\text{th}}$ to 28$^{\text{th}}$, and the cumulated rainfall reached 66.1 mm. Both this rain period and the above drought period were in the same vegetation period so that parameter a, used to evaluate ET_r through $ET_{0,r}$ (the subscript r represented the total value of the rain period, similarly hereinafter), could be assumed not to change in either period. Thus, the water budget of two soil layers during the rain period can be analysed by Eqs. (6) and (7), and the results are shown in Table 8. The runoff of SP was low to 0.6 mm and close to that of FC, which was consistent with the results of multiyear average analysis above. All values of $\Delta V_{\text{sum},r}$ were positive, and all values of Q_r were negative, which showed that the total soil water volume of both layers was supplied. The order of water storage in the top layer (i.e., $\Delta V_{\text{sum},r}$) under four treatments from high to low was as follows: SP > FC > BL > CK. The water supply to the bottom layer (i.e., $-Q_r$) decreased with an increase of vegetation coverage, which also means that higher vegetation coverage would reduce the risk of deep percolation. In short, SP was a recommendable treatment due to higher water supply to the top layer and lower water supply to the bottom layer.

CONCLUSION

The eight-year citrus field experiment result indicated that strip planting of grass and grass cover on citrus land in red soil slope, southern China can significantly reduce water runoff and soil erosion. In the same treatment, the mean soil moisture contents increased with depth in all seasons. In 3 of the 4 measured soil layers, the soil moisture contents of strip planting (SP) were the highest among all the treatments. The soil moisture contents of FC were lower than in SP because of higher water consumption by the grass cover.

Based on the Penman-Monteith model, the eight-year values and 2010 daily values of reference evapotranspiration were calculated. A method to evaluate actual evapotranspiration by soil moisture data was proposed: the Ross method was used to solve Richards' equation, and UCODE was employed as an evapotranspiration optimization tool. The results of water balance analysis also indicated that planting grass on citrus sloping land reduces surface runoff and increases infiltration water, but it would bring the risk of drought. In detail, the drought risk of SP was much lower than that of FC during the drought period, and SP contributed to storage of more water in the root zone during the rain period.

https://doi.org/10.17221/147/2017-SWR

It was concluded that planting grass on citrus sloping land was an effective management practice to reduce surface runoff and soil erosion, and increase water storage in the soil profile. Furthermore, among the two treatments with grass cover, strip planting of grass was better than full cover for soil and water conservation because of its lower water consumption.

Acknowledgments. We are grateful to Prof. L. Wu and Dr. T. Yang, University of California, Riverside for their helpful comments and suggested improvements to this paper.

References

Agus F., Garrity D.P., Cassel D.K. (1999): Soil fertility in contour hedgerow systems on sloping oxisols in Mindanao, Philippines. Soil & Tillage Research, 50: 159–167.

Allen R.G., Pereira L.S., Raes D., Smith M. (1998): Crop Evapotranspiration (Guidelines for Computing Crop Water Requirements). FAO Irrigation and Drainage Paper No. 56, Rome, FAO.

Basic F., Kisic I., Mesic M., Nestroy O., Butorac A. (2004): Tillage and crop management effects on soil erosion in central Croatia. Soil & Tillage Research, 78: 197–206.

Cook R.J. (2000): Advances in plant health management in the twentieth century. Annual Review of Phytopathology, 38: 95–116.

Curtis M.J., Rider D.E., Fristensky A., Claassen V.P. (2009): Cumulative sediment, nitrogen and phosphorus losses from bare and compost-amended fill slopes. Compost Science & Utilization, 17: 25–30.

Gao X.D., Wu P.T., Zhao X.N., Wang J.W., Shi Y.G., Zhang B.Q., Tian L., Li H.B. (2013): Estimation of spatial soil moisture averages in a large gully of the Loess Plateau of China through statistical and modeling solutions. Journal of Hydrology, 486: 466–478.

Harter T., Hopmans J.W. (2004): Hydrology-review, opportunities and challenges. In: Feddes R.A., de Rooij G.H., van Dam J.C. (eds.): Unsaturated-zone Modeling: Progress, Challenges and Applications. Dordrecht, Kluwer Academic.

Kinnell P.I.A. (2005): Raindrop-impact-induced erosion processes and prediction; a review. Hydrological Processes, 19: 2815–2844.

Lal R. (1989): Agroforestry systems and soil surface management of a tropical alfisol II: water runoff, soil erosion, and nutrient loss. Agroforestry Systems, 8: 97–111.

Liang Y., Li D.C., Lu X.X., Yang X., Pan X.Z., Mu H., Shi D.M., Zhang B. (2010): Soil erosion changes over the past five decades in the red soil region of southern China. Journal of Mountain Science, 7: 92–99.

Liu B.X., Shao M.A. (2014): Estimation of soil water storage using temporal stability in four land uses over 10 years on the Loess Plateau, China. Journal of Hydrology, 517: 974–984.

Liu Y., Tao Y., Wan K.Y., Zhang G.S., Liu D.B., Xiong G.Y., Chen F. (2012): Runoff and nutrient losses in citrus orchards on sloping land subjected to different surface mulching practices in the Danjiangkou Reservoir area of China. Agricultural Water Management, 110: 34–40.

Liu Y.J., Yang J., Hu J.M., Tang C.J., Zheng H.J. (2016a): Characteristics of the surface-subsurface flow generation and sediment yield to the rainfall regime and land-cover by long-term in-situ observation in the red soil region, Southern China. Journal of Hydrology, 539: 457–467.

Liu Z., Zha Y.Y., Yang W.Y., Kuo Y.M., Yang J.Z. (2016b): Large-scale modeling of unsaturated flow by stochastic perturbation approach. Vadose Zone Journal, 15: 1–20.

Nigo-Mbogba M., Yemefack M., Nyeck B. (2015): Assessing soil quality under different land cover types within shifting agriculture in South Cameroon, Soil and Tillage Research, 150: 124–131.

Poeter E.P., Hill M.C. (1998): Documentation of UCODE, a Computer Code for Universal Inverse Modeling. Water-Resources Investigations Report 98-4080. Denver, US Geological Survey.

Ross P.J. (2003): Modeling soil water and solute transport – fast, simplified numerical solutions. Agronomy Journal, 95: 1352–1361.

Roundy B.A., Farmer M., Olson J., Petersen S., Nelson D.R., Davis J., Vernon J. (2017): Runoff and sediment response to tree control and seeding on a high soil erosion potential site in Utah: evidence for reversal of an abiotic threshold. Ecohydrology, 10: e1775.

Schaap M.G., Leij F.J., van Genuchten M.T. (2001): ROSETTA: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. Journal of Hydrology, 251: 163–176.

Shi Z.H., Chen L.D., Cai C.F., Li Z.X., Liu G.H. (2009): Effects of long-term fertilization and mulch on soil fertility in contour hedgerow systems: a case study on steeplands from the Three Gorges Area, China. Nutrient Cycling Agroecosystems, 84: 39–48.

Shi Z.H., Yue B.J., Wang L., Fang N.F., Wang D., Wu F.Z. (2012): Effects of much cover rate on interrill erosion processes and the size selectivity of eroded sediment on steep slopes. Soil Science Society of America Journal, 77: 257–267.

Tucker D.P.H., Erickson C.G., Morgan K.T. (1997): Middles management methods in citrus affect soil moisture retention and vegetation species. Proceedings of the Florida State Horticultural Society, 100: 39–43.

https://doi.org/10.17221/147/2017-SWR

van Genuchten M.T. (1980): A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal, 44: 892–898.

Wang L., Tang L.L., Wang X., Chen F. (2010): Effects of alley crop planting on soil and nutrient losses in the citrus orchards of the Three Gorges Region. Soil & Tillage Research, 110: 243–250.

Wang Z.Y., Zuo C.Q., Cao W.H., Yang J., Xu Y.N., Qin W., Zhang J.F. (2011): Physical and chemical properties of soil under different vegetation restoration models in red soil hilly region. Acta Pedologica Sinica, 4: 715–724. (in Chinese)

Western A.W., Zhou S.L., Grayson R.B., McMahon T.A., Bloschl G., Wilson D.J. (2004): Spatial correlation of soil moisture in small catchments and its relationship to dominant spatial hydrological processes. Journal of Hydrology, 286: 113–134.

Wilson G.V., McGregor K.C., Boykin D. (2008): Residue impacts on runoff and soil erosion for different corn plant populations. Soil & Tillage Research, 99: 300–307.

Xia L.Z., Liu G.H., Wu Y.H., Ma, L., Li Y.D. (2015): Protection methods to reduce nitrogen and phosphorus losses from sloping citrus land in the Three Gorges Area of China. Pedosphere, 25: 478–488.

Zha Y.Y., Shi L.S., Ye M., Yang J.Z. (2013): A generalized Ross method for two- and three-dimensional variably saturated flow. Advances in Water Resources, 54: 67–77.

Zheng J.Y., Wang L.M., Shao M.A., Wang Q.J., Li S.Q. (2006): Gully impact on soil moisture in the gully bank. Pedosphere, 16: 339–344.

Zhu J.T., Mohanty B.P. (2002): Upscaling of soil hydraulic properties for steady state evaporation and infiltration, Water Resources Research, 38: 1178–1190.

Received for publication June 28, 2017
Accepted after corrections June 29, 2018
Published online November 23, 2018