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Original Research Paper

Study on the Influential Factors of SCS-CN Model Parameter *S* in the Loess Plateau area

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ABSTRACT

SCS-CN method, developed by the U.S. Department of Agriculture, is simple, effective and can be used in the area having lack of rainfall process data, thus has been widely used to estimate the runoff. In this study, 213 runoff events from 9 plots at Zizhou located on the Loess Plateau area, were studied and applied to calibrate water storage capability of soil which is donated as *S* in the SCS-CN method. The influence factors of *S* parameter were then analysed. The results show that the main influence factor of *S* is initial abstraction I_a. The initial abstraction ratio (I_a / *S*) at Tuanshangou watershed is 0.03. The maximum 30-minute rainfall intensity, 5-day prior rainfall amount and soil moisture in the top 20 cm soil layer has no influence on the *S* parameter.

INTRODUCTION

Since rainfall and runoff are the main drivers of water erosion of soil, quantitative calculation of runoff volumes under different underlying surface conditions is the key to soil erosion prediction. The Soil Conservation Service Curve Number (SCS-CN) is an empirical hydrological model developed by the Natural Resources Conservation Service of the United States Department of Agriculture (USDA) in the early 1950s (USDA, NRCS 1956). This model has few parameters and enables simple calculation, and has been less widely applied in the United States and some European countries (Mack 1995, Botan 1997, Auerswald 1996, Mishra 1999). Furthermore, its method for calculating runoff volume has been applied in a number of models, e.g., the Chemicals, Runoff and Erosion from Agricultural Management Systems model (CREAMS)(Knisel 1980), Agricultural Nonpoint Source Pollution model (AGNPS) (Leonard 1986), Erosion Productivity Impact Calculator model (EPIC) (Young 1989) and Simulator for Water Resources in Rural Basins model (SWRRB) (Williams 1990). Parameter *S*, which represents water storage capability of soil, is an important parameter of the SCS-CN model, and the influence of initial abstraction I_a on *S* has been extensively studied, with the initial abstraction ratio I_a/S (i.e., λ) determined as 0.2 (USDA ,NRCS 1956). However, other experimental information shows that λ varies from 0.00 to 0.30 with region (Arnold 1993, Cazier 1984, Bosznay 1989). The SCS-CN model has also been widely applied and modified in China. Using information of Suide runoff plots in the Loess plateau, Huang et al. (Huang 2007) determined that it was more reasonable to set the initial abstraction ratio λ as 0.001 and further established a linear relationship between antecedent moisture condition (AMC) and soil moisture, as well as a nonlinear relationship between topsoil moisture (depth: 0-15 cm) and *CN* value. In addition, based on plot information of Xindiangou in the Suide County of the Loess Plateau, Wang et al. (1995) optimized the λ value as 0.01 to adapt to three land uses for the area.

The Loess Plateau has serious soil erosion and clastic terrain, with rainfall and runoff as the main drivers of soil erosion. Although the SCS-CN model has been used to optimize parameter *CN* and λ values in this area (Wang & Huang, 2008, Luo 2002, Zhang 2008), the impact of water storage capability of soil (*S*) after runoff yield on runoff depth has not yet been studied. Therefore, the SCS-CN model was employed to analyse rainfall process information of Zizhou runoff plots in the Loess Plateau, calculate the *S* value and identify the main factors that influence *S* after runoff yield in the Loess Plateau. From this the relationship between *S* versus *Q* (discharge) was established to provide reference for predicting runoff volume in ungauged areas.

FUNDAMENTALS OF SCS-CN MODEL

The fundamental framework of the SCS-CN model consists of the Mockus's method (Mockus 1949) for calculating runoff from the empirical rainfall-runoff relationship diagram and

Andrews's (Andrews 1954) soil-vegetation-land use graphical method. Fundamentals of this model are as follows:

The model is based on the water balance equation and two fundamental assumptions. The first fundamental assumption is that the ratio of actual basin runoff volume (Q) to the maximum potential runoff volume (P-I_a, where P is rainfall) is equal to the ratio of actual infiltration capacity (F) to water storage capability of soil after runoff yield (S). The other assumption is that initial abstraction (I_a) is part of the water storage capability of soil after runoff yield (S). These statements can be expressed respectively in mathematical equations as follows:

$$P = I_a + F + Q \quad ...(1)$$

$$\frac{Q}{P - I_a} = \frac{F}{S} \quad ...(2)$$

$$I_a = \lambda \cdot S \quad ...(3)$$

From Eqs. (1) and (2), it follows that:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad ...(4)$$

The USDA NRCS analysed a great number of long-term experimental results and obtained an empirical relational expression for I_a and S: $I_a = 0.2\,S$, i.e., the proportional coefficient $\lambda = 0.2$, hence it follows that:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad P > 0.2S \quad ...(5a)$$

$$Q = 0 \qquad P \le 0.2S \quad ...(5b)$$

The empirical conversion relational expression for S and CN is:

$$S = 25400/CN - 254 \quad ...(6)$$

Where, P is rainfall (mm); Q is runoff depth (mm); I_a is initial abstraction (mm); S is water storage capability of soil (including initial abstraction) after runoff yield (mm); and λ is initial abstraction ratio. The curve number (CN) is a non-dimensional and main parameter of the SCS-CN model, and it is related to such factors as AMC, soil type, land use and gradient. The CN value ranges from 0 to 100, though under actual conditions, normally varies from 30 to 100.

INFORMATION AND METHODOLOGY

Overview of study area: We studied runoff information from 213 individual rainfall events over the Tuanshangou (Shejiagou) test plot which belongs to Zizhou runoff plot located in the Loess Plateau. The maximum 30 min rainfall intensity and soil moisture data at a soil depth of 0-20 cm measured in Plot 2 were also available. The former Shejiagou runoff area located at Shejiagou Village, Sanchuankou Commune, Zizhou County of the Shaanxi Province in China was renamed the Tuanshangou runoff area in 1962. Observations in the Zizhou runoff gauging station started in 1959 and stopped in the 1970s. Data of nine runoff plots were chosen for study, namely, Plots 2, 3, 4 and 5 located on the hillock slope on the left bank of loess hills, Plots 7 and 12 located on the gully hillock slope on the left and right banks of loess hills, respectively, Plots 8 and 9 located on the gully slope and Gouzhang shallow depression on the right bank of loess hills, respectively, and Plots 10 and 11 located on the gully hillock slope on the right bank of loess hills. The soil is mainly loessial soil and the main land type is farmland. Information on various runoff plots was collected from 1961 to 1969. The general information on the test plots is listed in Table 1.

Calculation of parameters I_a and S: Runoff volume (Q) depends on rainfall and the water storage capability of soil. In the early stage of rainfall, some rainfall will not give rise to runoff because of antecedent loss, i.e., initial abstraction (I_a), which is equivalent to water volume lost during rainfall runoff, including intercepted, evaporated, depression-filling and infiltrated water. S is the water storage capability of soil after runoff yield, that is, the water storage capacity of a basin, consisting of infiltrated water before runoff and water held until soil moisture saturation. We determined I_a and S using data analytics (Woodward 2003). Based on hourly rainfall runoff information from 213 rainfall events observed in the basin, rainfall prior to runoff was excluded as initial abstraction I_a (which underestimates initial abstraction) and S was calculated from I_a, i.e., $S = \frac{(P - I_a)^2}{Q} - (P - I_a)$, thereby the S value of every individual rain event was obtained. This method requires a detailed information series of individual rain runoff, which is unavailable for many runoff test plots. However, for long-term rainfall runoff information, this is a relatively trustworthy method to estimate I_a and S values.

Calculation of antecedent influential rainfall P_5 : In the SCS-CN model, the impact of antecedent precipitation on runoff is taken into account, and rainfall in the first five days of an individual rain event was used to determine yearly individual rainfall over each runoff plot. SCS-CN classifies AMC into three classes, AMC-I denotes arid conditions, AMC-II denotes average conditions, and AMC-III denotes wet conditions (Mockus 1949). The AMC values of the basin during the vegetation growth season and fallow period are given in Table 2.

Since, in this study, the S value was determined using

Table 1: General information of the Tuanshangou test plots.

Name	Gradient (%)	Slope length (m)	Land use type	Data period	Number of Rainfall events
plot 2	40.4	40	Farmland, potato, millet, legumes	1961-1967	25
plot3	40.4	60	Farmland, potato, millet, legumes, alfalfa	1961-1969	29
plot4	40.4	20	Potato, millet, legumes	1963-1967	21
plot5	60.1	20	Potato, millet, legumes	1963-1967	20
plot7	173.0	20.025	Farmland+barren slopes,potato, alfalfa, millets, legumes	1961-1969	32
plot9	173.0	20	Pea, proso millets, sorghum, alfalfa, millets, legumes	1963-1969	28
plot10	62.5	30	pea, wheat	1966-1967	10
plot11	62.5	15	pea, wheat	1966-1967	10
plot12	-	-	laterite scarps, alfalfa, black beans	1965-1969	38
sum					213

Table 2: AMC values during the vegetation growth season and fallow period.

AMC	Rainfall in the first five days (mm)	
	Fallow period	Growth period
I	<13	<36
II	13~28	36~53
III	>28	>53

data analytics instead of curve number *CN*, relationships between rainfall during the first 5 days (P_5) and *S* under AMC-I conditions for various land uses were selected to study the impact of AMC on *S*; the AMC-I condition was chosen because the study area is located in an arid to semi-arid climate region, and there were few cases in which total precipitation exceeded 36 mm during the first 5 days (except wheat land under AMC-II conditions) even during the growing period. Since runoff process information over the study area was acquired during the plant growing period, rainfall in the first 5 days of the growing period was selected to classify AMC.

RESULTS AND ANALYSIS

Water storage capacity *S* of a basin is related to a number of factors such as soil characteristics, terrain and land use. In this paper, Plots 2-11 were loessial soil, and in terms of terrain, the impacts of gradient and slope length on runoff depth were considered. Thus, Plots 4 and 5 with identical slope length and land use and Plots 2 and 3 with identical gradient and land use were chosen to compare runoff depth, as shown in Figs. 1(a) and (b).

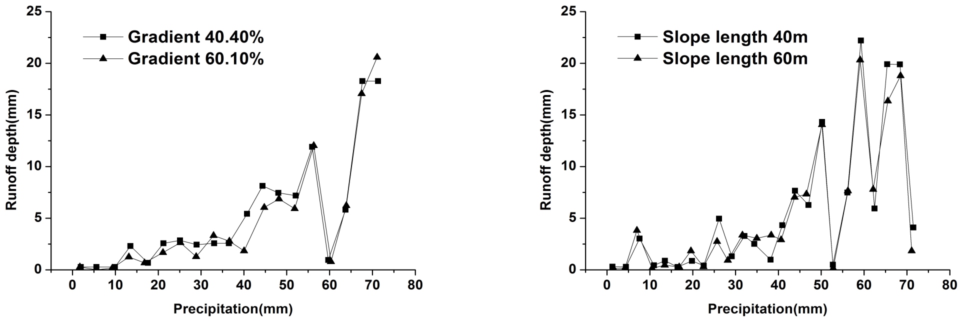
Fig. 1(a) compares runoff depth between Plots 4 and 5 with different gradients after 19 rainfall events, resulting in a mean relative error of 32.9% and absolute error range of 0 to 3.7 mm; Fig. 1(b) compares runoff depths between Plots 2 and 3 with different slope lengths after 23 rainfall events, resulting in a mean relative error of 49% and absolute error range of 0 to 3.6 mm. Therefore, runoff depths were basically the same under different gradient and slope length conditions, thus gradient and slope length had no impact on runoff depth. Consequentially, another influential factor, land use, was studied to determine the ultimate *S* value of the basin.

Land use status of the study area showed ten types of farmland use, namely, potatoes, millets + legumes, proso millets, alfalfa, wheat + proso millets + millets + black beans, farmland, peas, wheat, farmland + barren slopes, laterite scarps + alfalfa and black beans. In such cases of land use, the impacts of initial abstraction (I_a), antecedent influential rainfall (P_5), maximum 30 min rainfall intensity (I_{30}) and topsoil moisture on the *S* value were studied.

Relationship between initial abstraction (I_a) and water storage capability of soil (*S*): Fig. 2 shows the linear curves of I_a versus *S* under different land use conditions, demonstrating that the correlation coefficients of I_a versus *S* linear curves were above 0.5 in four land use types, namely, potatoes, millets + legumes, alfalfa and farmland. The I_a versus *S* correlation coefficients ranged from 0.2-0.5 in other four land use types, namely, proso millets, wheat + proso millets + millets + black beans, farmland + barren slopes, and laterite scarp + alfalfa and black beans. I_a and *S* also exhibited no obvious linear correlation in two land use types, namely peas and wheat. This was likely because runoff information on Plots 10 and 11 was only available in 1966 and 1967; furthermore, the two plots were close each other but far from other plots, so the data used differed to some extent.

According to the established linear regression equations for I_a and *S*, proso millets, peas, wheat, and farmland + barren slope land use did not pass the significance test at 0.1, while for the remaining equations that did pass the significance test, slopes ranged from 0.01 to 0.05 and intercepts ranged from 0.5 to 6; therefore, the mean of slopes (0.03) was taken as the λ value of this study area.

Hence, initial abstraction I_a had a linear correlation with



(a) (b)

Fig. 1: Comparison of runoff depth at different gradients and slope lengths.

Table 3: Linear relationships between P_5 and S under various land use conditions.

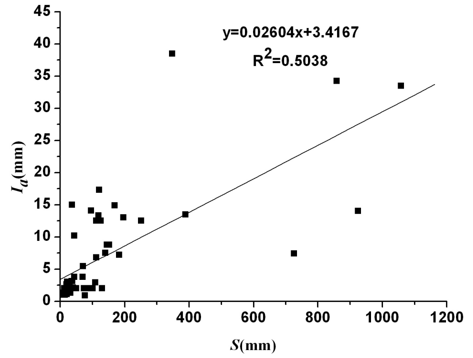
Land use type	Linear regression equation	R^2	*t* test
Potato	$P_5 = -0.0059S + 12.223$	0.0213	0.302
Millets + legumes	$P_5 = -0.0045S + 13.383$	0.0039	0.751
Proso millets	$P_5 = -0.1007S + 17.519$	0.9942	0.003
Alfalfa	$P_5 = -0.0003S + 11.187$	2E-05	0.985
Wheat + proso millets + millets + black bean	$P_5 = -0.0126S + 12.681$	0.073	0.330
Farmland	$P_5 = -0.0321S + 20.67$	0.8867	0.058
Pea	$P_5 = 0.0609S + 4.1238$	0.227	0.117
Wheat	$P_5 = -0.0208S + 47.12$	0.359	0.209
Farmland +barren slopes	$P_5 = 0.005S + 0.4438$	0.2821	0.469
Laterite scarps + alfalfa and black beans	$P_5 = 0.0083S + 9.6097$	0.0358	0.299

Table 4: Linear relationships between I_{30} and S under various land use conditions.

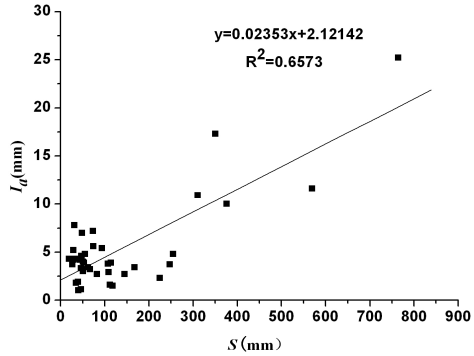
Land use type	Linear regression equation	R^2	*t* test
Potato	$I_{30} = -0.0133S + 36.645$	0.0181	0.323
Millets + legumes	$I_{30} = -0.0096S + 27.156$	0.0206	0.371
Proso millets	$I_{30} = 0.2685S + 3.6496$	0.8873	0.005
Alfalfa	$I_{30} = 0.0082S + 31.238$	0.0036	0.841
Wheat + proso millets + millets + black bean bean	$I_{30} = -0.0008S + 36.758$	7E-06	0.993
Farmland	$I_{30} = 0.0111S + 22.91$	0.463	0.320
Pea	$I_{30} = 0.1256S + 39.284$	0.1553	0.205
Wheat	$I_{30} = -0.0086S + 25.227$	0.018	0.751
Farmland +barren slopes	$I_{30} = 0.0036S + 18.337$	0.0036	0.940
Laterite scarps + alfalfa and black beans	$I_{30} = -0.0338S + 29.468$	0.1181	0.035

S, and the ultimately determined initial abstraction ratio λ of the Tuanshangou basin under different land use types was 0.03, which differs dramatically from the λ value of 0.2 recommended by the USDA NRCS, indicating that λ varies with regional natural geographical circumstances and hydrological conditions.

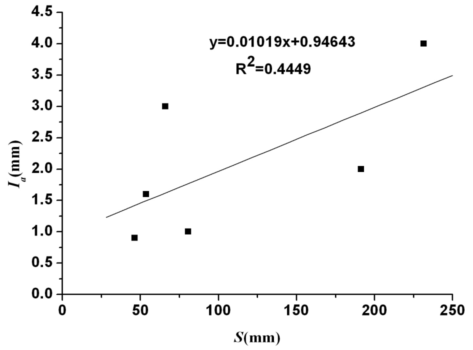
Relationship between antecedent influential rainfall (P_5) and water storage capability of soil (S): Linear relationships between P_5 and S under various land use conditions established in Table 3 demonstrated that, under potatoes, millets + legumes, alfalfa, wheat + proso millets + millets + black beans, peas, wheat, farmland + barren slopes, and laterite scarp + alfalfa and black beans land use conditions, the linear correlation coefficients R^2 were less than 40% and failed the coefficients of determination significance test at 0.1; whereas, under proso millets and farmland, the linear



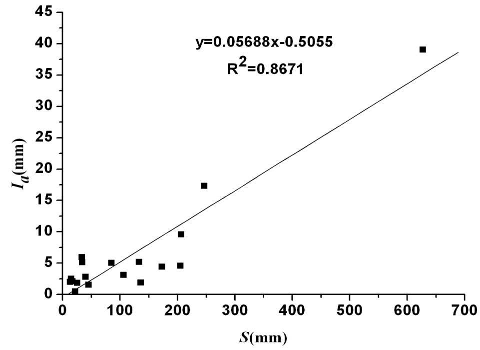
Potatoes



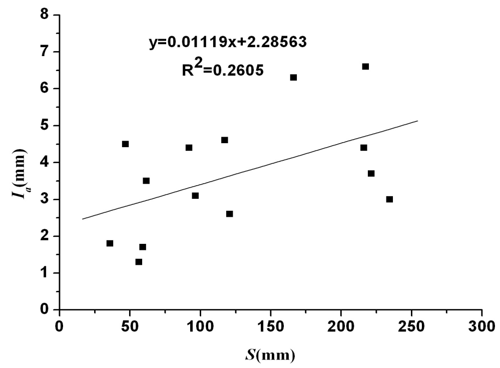
Millets+legunes



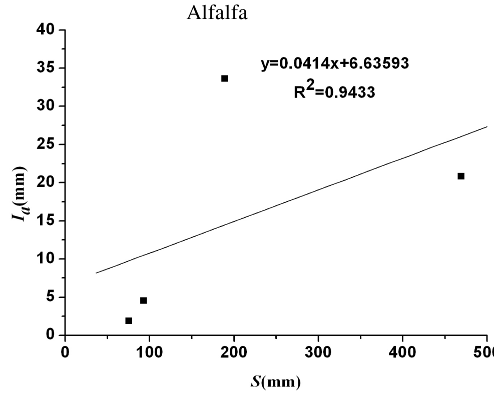
Proso millets



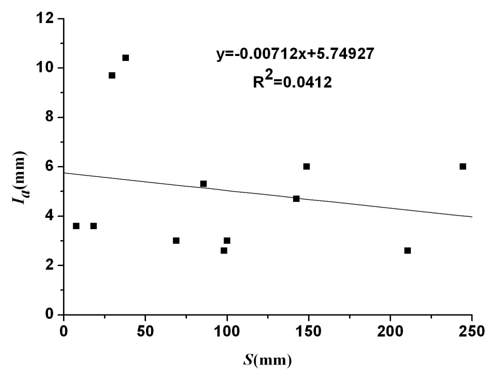
Alfalfa



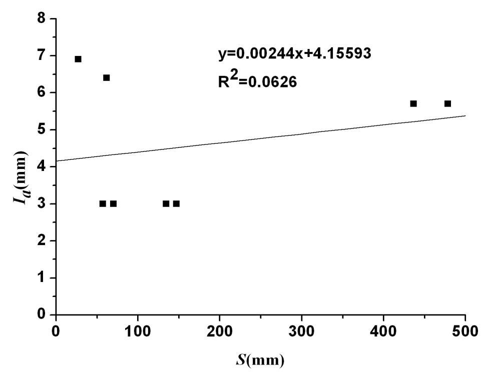
Wheat + proso millets + millets + black bean



Farmland

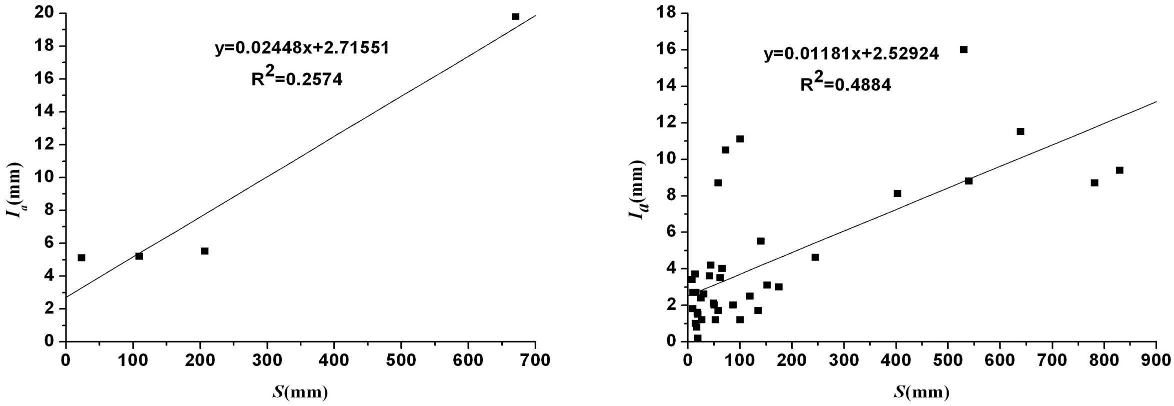


Peas



Wheat

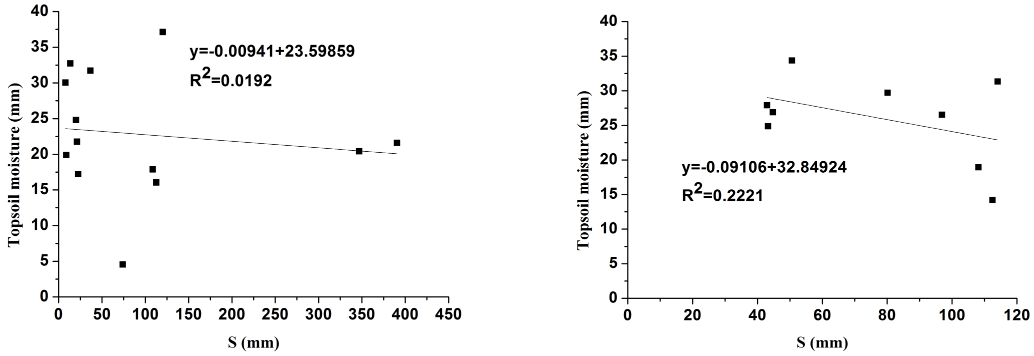
Cont....



Farmland + barren slopes

Laterite scarp + alfalfa and black beans

Fig. 2: I_a versus S curves under different land use conditions.



Potatoes

Millets+legunes

Fig. 3: Relationship curves for topsoil moisture (0-20 cm depth) versus *S* under various land use conditions.

correlation coefficients R^2 were greater than 80% the coefficients of determination and passed the significance test at 0.1, mainly because the relationship curves for these two land use types had fewer data points (three and six points, respectively, compared with more than 10 data points for the other land use types). Therefore, P_5 and S did not follow a linear correlation relationship under different land use conditions, indicating that AMC had no significant impact on water storage capability of soil in the study area.

Antecedent moisture condition is one factor influencing *S* and runoff volume. As mentioned before, *CN* values of hydrological soil groups are varying with various land uses. Under AMC-II conditions, *CN* values can be estimated using *CN* Values Table, while under AMC-I and AMC-III conditions, *CN* values can be calculated using corresponding conversion equations. Hence, based on the *CN* values under different land use conditions, one can use Eq. [6] to determine *S* values for various land uses. In this study, data analytics were used to determine the *S* value, without relating to the curve number *CN*. Therefore, when studying the impact of AMC on *S*, one can select P_5 versus *S* relationships under various land use AMC-I conditions to generate a more simple and facile calculation.

Relationship between topsoil moisture and water storage capability of soil (*S*): Soil moisture at a soil depth of 0-20 cm was selected as the topsoil moisture. Because this measurement data were only available for Plot 2, this dataset was selected for analysis, although the results were not ideal. As shown in Fig. 3, for linear correlation curves established between *S* and soil moisture at a 0-20 cm depth under two land use type conditions, potatoes and millets + legumes, the maximum correlation coefficient was merely 0.2221, indicating no linear correlation relationship. Thus, topsoil moisture had no immediate impact on the water storage capability of soil in the study area.

Relationship between maximum 30 min rainfall inten-

sity (I_{30}) and water storage capability of soil (S): The maximum 30 min rainfall intensity during an individual rain event can reflect the effect of rainfall erosivity fairly well, and is assumed to a certain impact on runoff. Therefore, given the same land use, the relationship between I_{30} (mm/h) and water storage capability of soil S (mm) was studied. Linear relationships between I_{30} and S under various land use conditions are shown in Table 4.

Under various land use conditions, the maximum 30 min rainfall intensity I_{30} (mm/h) of individual rain events had no linear correlation relationship with corresponding water storage capability of soil S (mm). The correlation coefficient reached over 0.8 when the land use type was proso millets, which was mainly attributed to fewer data points, and thus negligible. Therefore, in the study area, I_{30} had no impact on the water storage capability of soil.

CONCLUSIONS

Application of the SCS-CN model to the Zizhou runoff area in the Loess Plateau indicated that gradient and slope length factors had no significant impact on runoff depth.

Under various land use conditions, initial abstraction (I_a) and water storage capability of soil (S) exhibited a linear correlation relationship, and the ultimately determined initial abstraction ratio λ value of the Tuanshangou Basin was 0.03, which differed dramatically from the λ value of 0.2 recommended by the USDA NRCS. The results indicated that λ values vary with regional differences in natural geographical circumstances and hydrological conditions.

Under various land use AMC-I conditions, P_5 and S had no obvious linear correlation, indicating that AMC had no significant impact on water storage capability of soil in the study area.

Under various land use conditions, topsoil (0-20 cm depth) moisture and maximum 30 min rainfall intensity (I_{30}) also had no significant impact on water storage capability of soil (S).

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