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Micro-Topographic Characteristics in Coordinate with Surface Erosion

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1. Introduction

In the process of water erosion, the transformation of surface morphology itself has an impact on the production of surface runoff, water flows, convergence, thereby affect the evolution of soil erosion types and erosion sediment yield (Burwell*, et al.,1968;* Johnson*, et al.,1979;* Onstad *et al.,1984*). From 1960s, many scholars had carried out a series of studies on the water erosion evolution process, including the research about surface morphology factors, measurement and design procedure, surface hydrological erosion processes and so on(Allmaras,*et al.*, 1972; Lehrsch, *et al.*, 1987; Wang, *et al.*, 2005). However, due to the randomness of surface topography in the process of erosion, there still had some limitation to people's understanding about the relationship between soil erosion and surface morphology(Huang, *et al.*, 1992, 2001, 2003) .

In this study, it simulated different surface erosion periods under different surface tillage micro-morphology. Based on the comparative analysis and quantitative study, the characteristic of micro-morphology with its response mechanism in coordinate with surface erosion was illustrated. The results would be helpful to promote understanding of soil erosion processes in depth.

2. Relative concepts

Soil surface morphology was the focus of this study, so it was necessary to have a specific definition about relative concepts.

2.1 Micro-topography

From the perspective of geography, geomorphology refers to the fluctuant forms in the Earth's surface, such as plains, basins, hills, plateaus, valleys, etc.. So the geomorphology was belong to a macroscopical term, it was also known as a large topography or terrain.

Relative to the megarelief, micro-topography means the undulating surface configuration with slight fluctuations of relative elevation (usually no more than 5-25 cm) in a relatively small area. It can be simplified to 3 kinds of terrains — the plane, slope and uneven terrain, which correspond to a row of probe points and their elevation values can be fitted into three kinds of two-dimensional geometric models — horizontal lines, diagonal lines and curves in the X-Z plane. The undulating terrain feature of micro-topography in loess tillage slope generated by human management is not only the direct result of slope soil erosion but also the important reason leading to the further development of slope erosion. It is a composite factor which can reflect various elements in dynamics of slope erosion as well as their interaction. Research on the topographical features and spatial variability of loess tillage slope has great significance in the formation and evolution of soil erosion and can provide data support for the construction of a prediction model which can reveal the transforming relationship between different erosion modes of the slope(Xue, *et al.*, 2008).

2.2 Micro-slope & micro-aspect

At the grid scale, micro-topography can be divided into uniform geographic grid cell. While the concept of micro-slope and micro-aspect mean the grid slope and grid aspect Micro-slope has the feature of relatively shallow depth, gentle terrain, and it could be extended to micro- topography.

It can be classified to 9 grades: <5 °, 5-10 °, 10-15°, 15-20°, 20-25°, 25-30°, 30-35°, 35-40°, >40°; while micro-aspect can be classified to 8 directions followed by true north, northeast, east, southeast, south, southwest, west, northwest.

3. Method

3.1 Experimental design

Experiments will be carried out in artificial simulated rainfall lobby of State Key Laboratory of Loess Plateau Soil Erosion and Dryland Farming (side-spray style automatic simulation rainfall system with nozzles height of 16m). is 2.0 m × 1.0 m × 0.5 m and the slope can be adjusted in the range of 0° ~ 30°.

Choose the sloping surface soil (0 ~ 20 cm) in Yangling District in Shaanxi Province for the experimental soil. Yangling District is located in the southern edge of the Loess Plateau with the longitude of 108.72° and the latitude of 34.36°, which belongs to the temperate semi-humid continental monsoon climate; its average annual rainfall is 637.6 mm. The soil type is the Loutu which is gray brown and loose with the granular or mass structure, and the soil particles are mainly silty sand. The main mechanical components are shown in Table 1.

Particle diameter / mm	Mechanical components / %	Particle diameter / mm	Mechanical components / %
＜0.001	36.28	0.05～0.25	2.70
0.001～＜0.005	12.89	＞0.25	0.12
0.005～＜0.01	6.88	Physical cosmid	56.05
0.01～＜0.05	41.13		

Table 1. Particle size distribution of the experimental soil in 0–20 cm depth

Tillage measures of artificial digging (AD), artificial backhoe (AB) and contour tillage (CT) are commonly used in loess slope farming, so these three kinds of tillage measures are arranged respectively in the corresponding etching tank to simulate different micro-topographic conditions. The main processes are as follows: 1) soil preparation: after the soil samples are dried, they are seived (mesh 0.5 cm), and filled in the soil tank with 8 layers (soil bulk density of 1.30 g/cm^3 and moisture content of 10%); 2) simulate different tillage measures including: ①contour tillage (CT): conduct the horizontal tillage on the slope surface in the direction which is perpendicular to the slope to form grooves and ridges with the ridge height of 7 ~ 10 cm and ridge distance of 30 cm; ②artificial digging (AD): use the pickaxe to dig on the surface with the depth of 5 ~ 8 cm and distance of 20 ~ 25 cm; ③artificial backhoe (AB): adopt backhoe to cultivate along the surface with the depth of 4 ~ 5 cm. Both AD and AB are gradually laid from the base of the hill to its top, forming undulating hills and depressions. Due to the impact of the slope and tillage modes, ridges and potholes formed by tillage have no spatial symmetry. In order to keep these tillage measures closer to natural conditions, farmers who have long been engaged in the same tillage are employed to set up these tillage measures. In order to make a comparison a linear slope is set as check (CK). Three rainfall intensities of 60 mm/h, 90 mm/h and 120 mm/h are selected and the slope is 15 °; two replications are set.

In the artificial rainfall experiment, sectional rainfall are carried out including 2 phases,: (1) before rain (BeR) stage: different micro-topographic forms has been prepared. (2) the phase when squama-like pits and small-scale overfall appear on the slope is called sheet erosion (S_hE).

3.2 Elevation data collect and represent

A laser range finder is used to measure the slope elevation informationin 2 sectional stages. The laser scanner has 3 parts: 1) XY table; 2) laser range finder (Leica Lai, the vertical error is less than 3 mm); 3) data acquisition and control system whose principle is similar to the gearing of dot-matrix printer. Each test sloping surface can obtain 3480 elevation points and each point represents the 0.02 m × 0.02 m range of the actual ground. These points have provided a high guarantee for the construction and application of high resolution data model as micro-topographic digital elevation model (M-DEM).

M-DEM is a continuous expressive method for the surface of micro-topography, which can reflect the undulating changes and trivial conditions. In recent years, with the development of geographic information system (GIS) technology(Tang, *et al.*, 2006), M-DEM has become the important data of regional soil erosion research. The setup procedure of M-DEM is as shown in Figure 1.

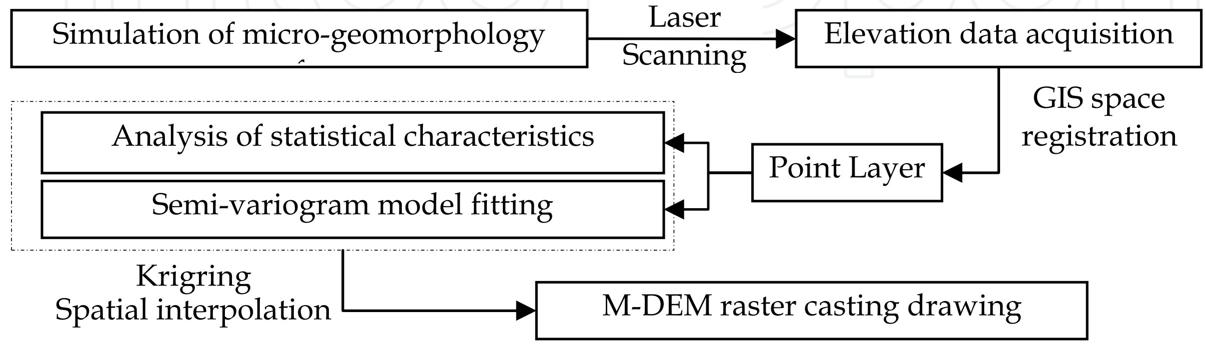

Fig. 1. The flow chart on elevation data collection and representation of the slope micro-topography

4. Results and analysis

4.1 Statistical characteristics of the relative elevation

4.1.1 Normal distribution test

According to the classical statistical methods, normal distribution test on the density distribution function of micro-topographic relative elevation probability of each tillage slope before rainfall is conducted using the single-sample KS method. Table 2 shows the statistical results of K-S test result on the significance level when α = 0.05. Accordingly, the elevation data can be used to generate M-DEMs.

Tillage slope	Mean /cm	Std. Dev.	Min /cm	Max /cm	Skewness	Kurtosis	Median /cm	K-S Z	Distribution pattern
AB	20.864	1.0622	17.8	24.1	-0.25078	2.5702	21.0	5.015	normal distribution
AD	22.170	1.2511	18.3	25.3	-0.2783	2.5735	22.3	4.744	normal distribution
CT	21.046	1.6965	17.1	24.3	0.0099255	1.8528	21.0	5.753	normal distribution

Table 2. The K-S test of density distribution function of micro-topographic relative elevation probability

4.1.2 Analysis of spatial variability

Semi-variogram fitting curve model is adopted to analyze and describe the structure characteristics of relative elevation spatial variability of micro-topography, as shown in Table 3.

Rainfall stage	Tillage measures	C_0 cm^2	C_0+C cm^2	$C/(C_0+C)$ %	semi-variance distance m	R^2	RSS	Model
BeR	AB	0.608	1.637	62.9	2.931	0.815	0.124	Exponential
	AD	0.409	1.677	75.6	0.492	0.93	0.097	Exponential
	CT	0.088	2.832	96.9	0.091	0.425	1.430	Spherical
	CK	0.021	0.145	85.5	1.782	0.962	5.151E-04	Exponential
S_hE	AB	0.434	0.959	54.7	1.683	0.759	0.074	Exponential
	AD	0.446	1.589	71.9	1.053	0.934	0.092	Exponential
	CT	0.006	1.54	99.6	0.101	0.534	0.432	Spherical
	CK	0.0384	0.2238	82.8	2.0386	0.936	8.654E-04	Gaussian

Table 3. Statistical attribute values of spatial variability characteristic parameters of loess slope micro-topographic relative elevation with the rainfall intensity 90 mm/h

Semi-variogram is a function chart of the distance, generally represented by the variation curve. In geostatistics, the fitting curve models, corresponding to semi-variogram, which are commonly used including: spherical model, exponential model, Gaussian model, pure nugget model, power function model, Di Weisheng model. Different model selection criteria are: the closer the determination coefficient R^2 is closer to 1, the reference value of related equation will be higher; the smaller RSS value is, the better the fitting degree of the fitting model using theoretical semivariogram will be.

The ratios of base effect $C/(C_0 + C) > 75\%$, 75% ~ 25%, and 25% respectively indicate that the spatial correlation of variables is high, medium, and weak (Zuo, *et al.*, 2010). From Table 3, we can know that: with the constant evolution of the erosion processes, the micro-topographic relative elevation of different tillage slopes are in line with the fitting curve model of semi-variogram, which can better reflect the spatial structure; the tillage slope is significantly affected by the anthropogenic factors and stochastic factors dominate the leading role. Generally, the relative elevation values of loess slope micro-topography show a medium or high correlation, whose spatial variability is affected by the combined structural and random factors.

The fitting curve models is the approximation expression of semi-variogram, so it is necessary to conduct cross-examination on model parameters. An advantage of the cross validation test method (a kind of indirect method that combines with ordinary kriging) is that in the examination process the selected model parameters will be modified constantly until they reach a certain degree of accuracy. The basic idea is: in turn assume each measured data point has not been determined and the selected semivariogram model is used to estimate the optimal as well as unbiased value of this point based on n-1 other measuring points applying ordinary kriging(*Yang, et al., 2010*). Then test the rationality of the model by analyzing the error. Krigring cross-examination characteristic value of loess slope micro-topographic relative elevational spatial variability is shown in Table 4.

	Rainfall	Regression coefficient	SE	r^2	Intercept	r
AB	BeR	1.021	0.007	0.866	-0.43	0.93
	ShE	1.023	0.007	0.874	-0.47	0.93
AD	BeR	1.125	0.01	0.784	-2.78	0.89
	ShE	1.098	0.008	0.828	-2.09	0.91
CT	BeR	1.111	0.004	0.95	-2.34	0.97
	ShE	1.065	0.005	0.929	-1.34	0.96
CK	BeR	1.033	0.007	0.867	-0.63	0.93
	ShE	1.029	0.008	0.842	-0.56	0.92

Table 4. Krigring cross-examination parameters of loess slope micro-topographic relative elevational spatial variability with the rainfall intensity 90 mm/h

The determination coefficient r^2 is an important indicator to measure the goodness-of-fit of the linear regression model. We usually use its square root - the correlation coefficient r to describe its relevance. When $|r| \geq 0.8$, it shows a high degree of correlation; when $0.5 \leq |r| < 0.8$, it shows the medium correlation; when $0.3 \leq |r| < 0.5$, it shows the low correlation; when $|r| < 0.3$, it is regarded as non-correlation(Yu, *et al.*, 2003). Accordingly, it shows that the semi-variogram fitting curve model can better fit the spatial variability of micro-topography. Krigring cross-examination and Krigring interpolation results of CT slope in BeR is shown as figure 2.

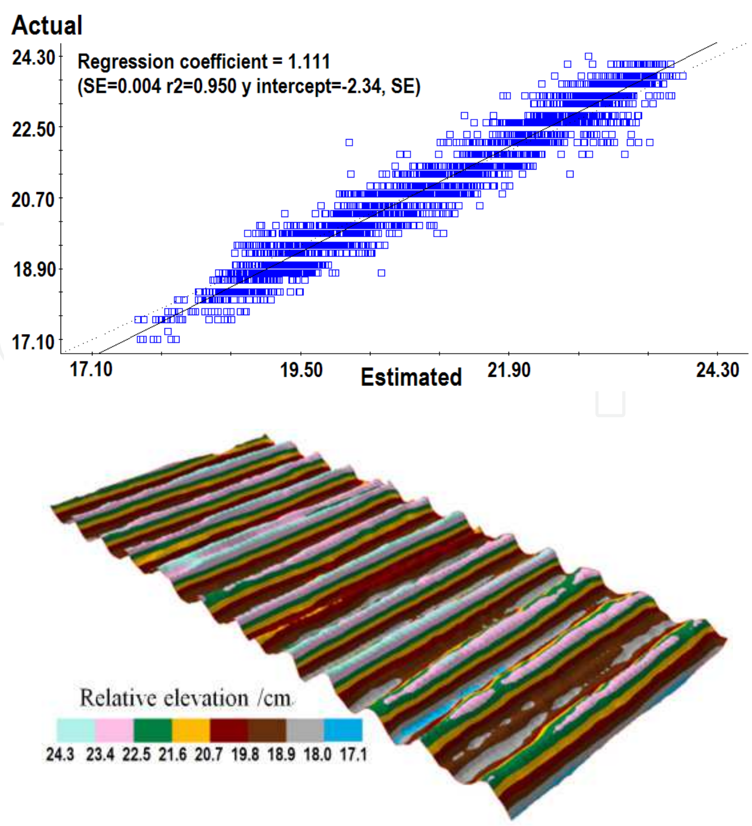

Fig. 2. Krigring cross-validation with its interpolation results of M-DEM of CT micro-topography in BeR.

4.2 Micro-topographic statistical characteristics

Based on the findings above it can be said that the corresponding fitted semi-variogram model can better reflect the spatiotemporal variability of micro-topography after kriging. So, the method can be safety adopted at the application of the micro-topography with the rainfall intensity 60 mm/h and 120 mm/h. The statistical frequency of surface elevational points at different height classes under different tillage practice is shown at figure 3.It shows that the distribution of elevational points at different height classes under different tillage practice are significantly different.

On CK surface, elevational points values are more concentrated than other tillage, and 98% of the them are concentrated in the range of 0.22 ~ 0.24 mm. Correspondingly, its peak frequency is at 0.23 mm; On AH and AD surface, account for about 49.1% and 37.0% elevational points are concentrated in the range of 0.22 ~ 0.26 mm, and their peak frequency of the elevation are at 0.24 and 0.25 mm separately; On CT surface, accounts for 37.4% elevational points values are concentrated in the range of 0.20 ~ 0.24 mm, and its peak frequency is at 0.22 mm; Compared with CK, the statistical frequency of the surface elevation distribution of other micro-topographys are in weak variability and the curve approximately followed the normal distribution.

The variation of elevation at different rainfall process is different. Compared with the BeR, in the ShE stage, the rainfall influence the distribution characteristics of surface elevation in the order of AD> CT>AH, and the rainfall has nearly no influence to CK surface.

Statistical characteristics of slope elevation are calculated (see Table 5) by classical analysis methods (Hillel, 1980). It indicates that the tillage and rainfall have an important impact on the micro-topographic surface.

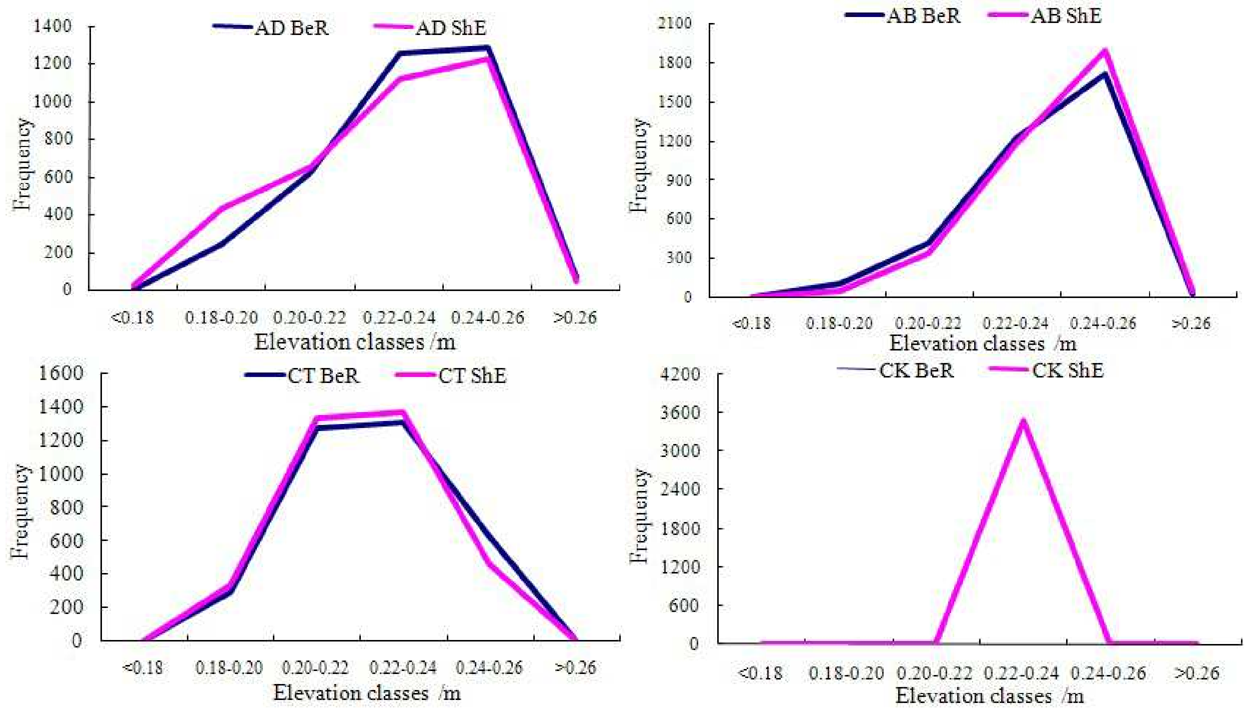

Fig. 3. Surface elevation distribution under different tillage

Due to smooth surface of CK, its $S_{\bar{d}}$ value is relatively small (0.005). While $S_{\bar{d}}$ value of CT, AD, AH surface decreased little separately after rainfall. Furth more, $S_{\bar{d}}$ value of CT surface reduced 22%. It shows the elevation distribution of the CT micro-topography tends to flattened overall in the ShE stage. Mean while, Cv value of CT surface is relatively high, and it shows that CT surface has a larger surface fluctuations than other tillage.

Statistical parameters	tillage	stage	
		BeR	ShE
Average $\bar{x}$ /m	CK	0.229	0.229
	CT	0.220	0.220
	AH	0.228	0.230
	AD	0.251	0.240
Standard deviation $S_{\bar{d}}$ /m	CK	0.005	0.005
	CT	0.018	0.014
	AH	0.008	0.007
	AD	0.009	0.008
Variation coefficient Cv	CK	0.022	0.022
	CT	0.082	0.063
	AH	0.035	0.030
	AD	0.036	0.033

Table 5. Statistical characteristics of slope elevation

4.3 Micro-slope characteristics

Grid number to different micro-slope under rainfall intensity of 60 mm/h and 120 mm/h is shown as Figure 4. It is known that grid number is mainly concentrated in the range of: (1) AD: micro-slope of 0° ~ 5° and 10° ~ 20° in the stage of BeR, micro-slope of 0° ~ 5° and 10° ~ 15° in the stage of ShE; (2) AH: micro-slope of less than 25°in the stage of BeR, and no more than 20°micro-slope of AH surface in the stage of ShE; (3) CT: micro-slope of 0° ~ 5°, 15° ~ 30°, greater than 40° in the stage of ShE; (4) CK: micro-slope of no more than 10° in the whole rainfall process.

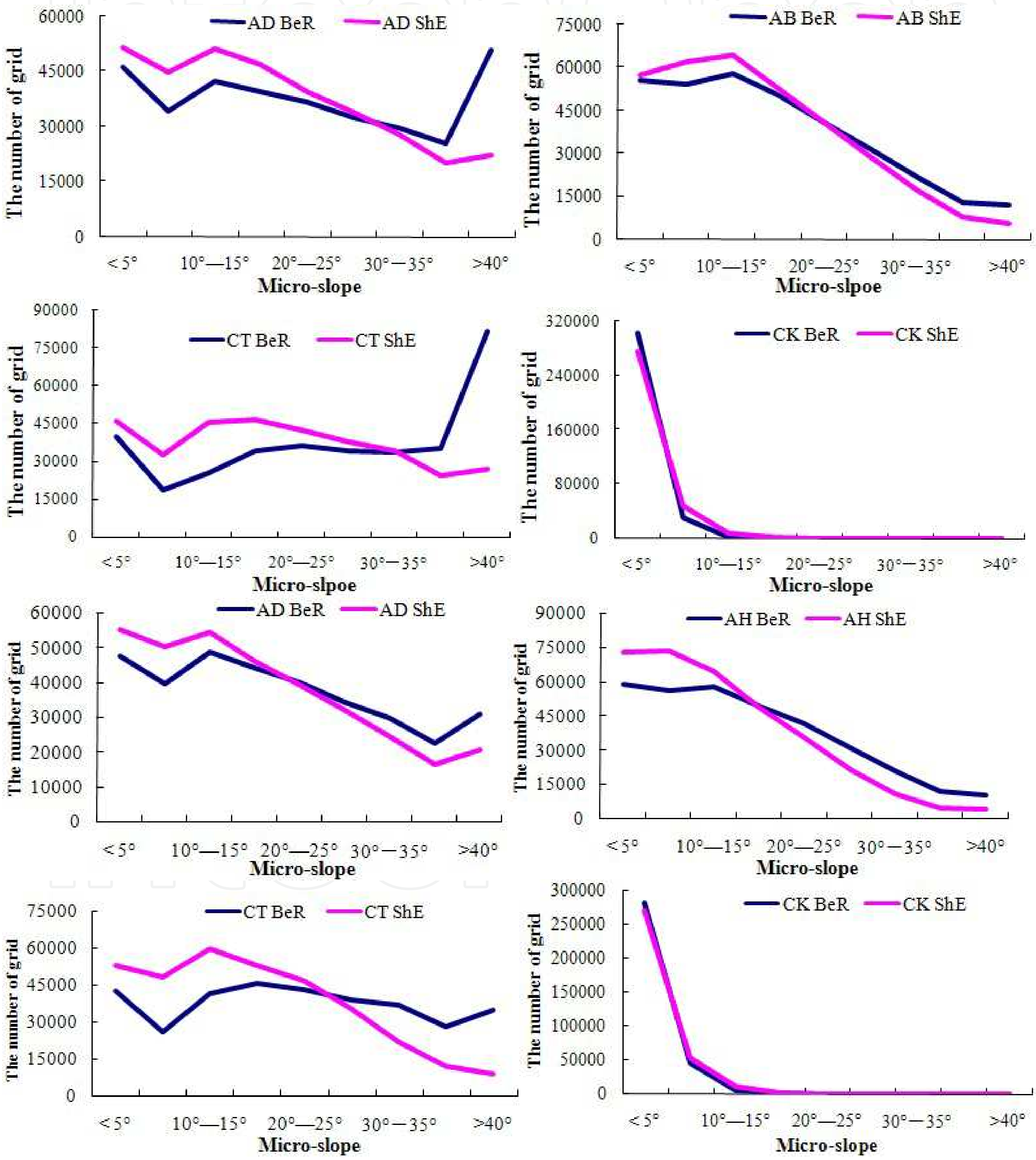

Fig. 4. Grid number to different micro-slope under rainfall intensity of 60 mm/h (A) and 120 mm/h (B)

Compared the feature in stage of BeR with which of ShE, it is known that the rainfall affect little to micro-slope on CK surface. The micro-slope grid number curve of AD, AH and CT surface present 'X-type', and they intersects at micro-slope 15° ~ 35° respectively. At the same time, with the increase of micro-slope, the statistical grid numbers shows decline trend generally. In addition, the intersection under 60 mm/h rainfall intensity is smaller than which under 120 mm/h rainfall intensity.

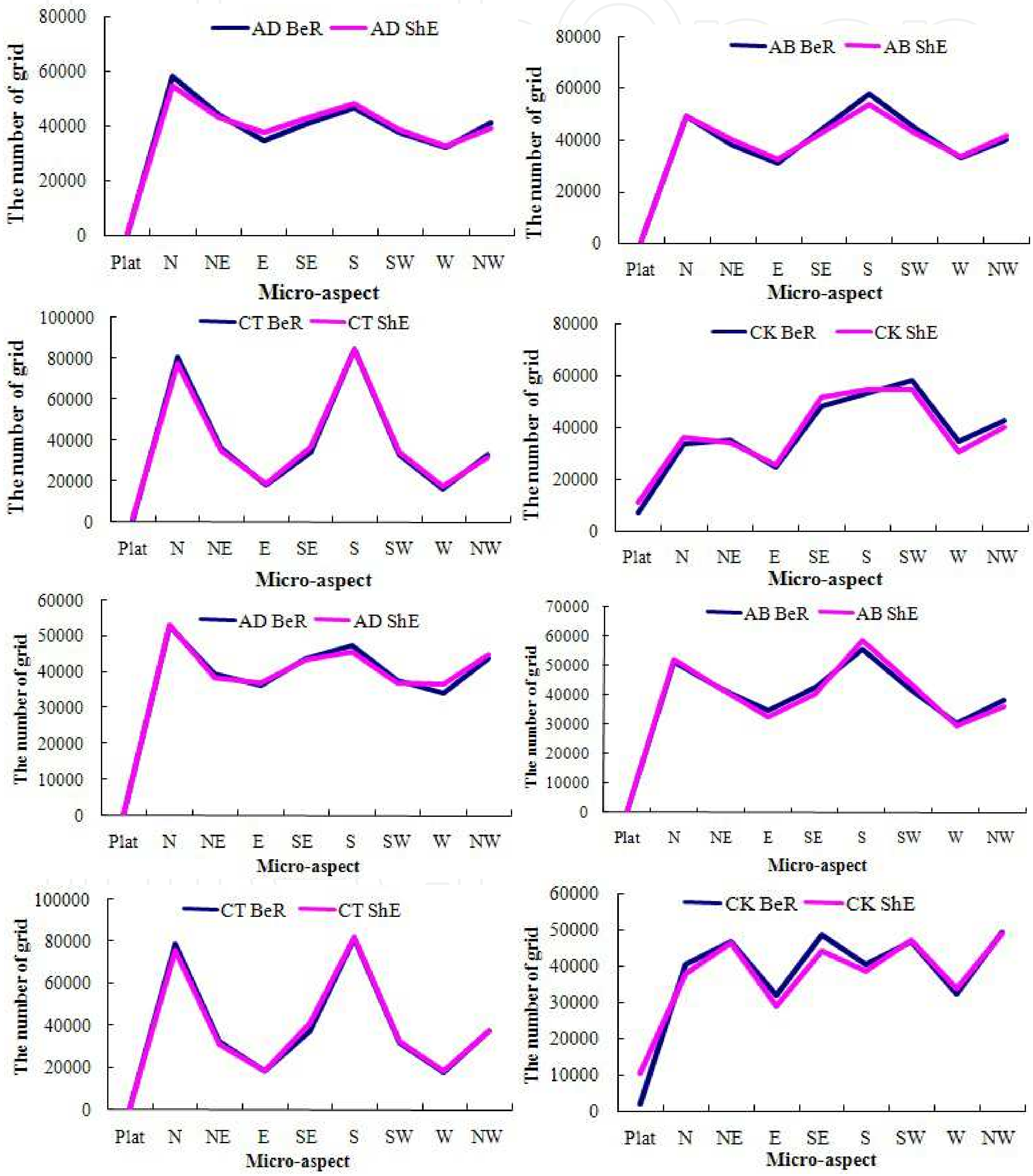

Fig. 5. Statistical grid number of surface micro-aspect under different tillage and rainfall intensity of 60 mm/h (A) and 120 mm/h (B)

4.4 Micro-aspect characteristics

Statistical grid number of surface micro-aspect under different tillage and rainfall intensity is shown as Figure 5. Compared with CK, the micro-aspect spatial distribution of AD, AH, and CT surface is significantly different. CT surface micro-aspect is mainly the direction of south or north, while AH and AD surface micro-aspect are the phenomena of contagious distribution at all directions.

At the same time, the 2 grid number curves of surface micro-aspect before and after rainfall are almost overlapped. It shows that though the rainfall can lead to change of surface micro-topography, it has little effect on the micro-aspect. Surface micro-aspect has the same trend of grid distribution whether it is under the rainfall intensity of 120 mm/h or 60 mm/h.

5. Conclusions

This paper analyzes the relative elevation variability of micro-topography in 3 typical farming slopes under rainfall intensity of 90 mm/h. and uses the single sample K-S to determine whether the density distribution of relative elevation probability belongs to the normal distribution. On this basis, classical statistical methods are adopted to analyze and describe the spatial variability characteristics. The results have shown that the density distribution functions of relative elevation densities of different tillage slopes are subject to the normal distribution which also have the spatial autocorrelation with weak variation. Secondly, the semi-variogram function is used to analyze the structure characteristics of relative elevation spatial variability of various micro-topography and the fitting curve model to conduct cross-examination. Studies have shown that: With the constant evolution of erosion processes, the semi-variogram fitting curve model can better reflect the variability characteristics of spatial structure of micro-topographys; On the whole, the loess slope micro-topography shows a medium or high correlation, whose spatial variability is jointly affected by the structural and random factors. Thirdly, the law of spatial self-correlation of micro-topographic relative elevation with the evolution of erosion. The results have shown that: the spatial correlation of loess slope micro-topographic relative elevation is generally shown as moderate and high self-correlation, and the index model can highly simulate the relative elevation changes of these micro-topographies. The experimental study on the micro-spatial variability of micro-topographic relative elevation has provided a reference for the further research on the micro-topography change coordinated with soil erosion.

Simultaneously, the definition of micro-topography, micro-slope, micro-aspect are firstly proposed. Based on the laboratory artificial simulated rainfall experiments, combining Laser scanning with GIS analysis, quantitative analysis about the micro-geomorphology characteristics are carried out. The results showed that:

In the ShE stage, the elevation distribution of the micro-geomorphology tends to flattened overall, and the rainfall influence the distribution characteristics of surface elevation in the order of AD> CT>AH;

Rainfall has little influence to micro-slope on CK surface. The micro-slope grid number curve of AD, AH and CT surface present 'X- type', and they intersects at micro-slope 15°~35° respectively;

The rainfall can lead to the transformation of surface micro-topography, but it has little influence to the micro-aspect. Forthmore, surface micro-aspect has the same trend of grid distribution whether it is under the rainfall intensity of 120 mm/h or 60 mm/h. All of these could provide theoretical basis for the in-depth study of mechanism and process of soil erosion.

Data used in this project are collected at micro-topography level, and the corresponding M-DEMs are taken as the basic research subjects. Also these M-DEMs are built at the stage of pre- and after-rain. In this study, it mainly reveal the characteristics of micro-topography in coordinate with surface erosion. In future, the project will expand to gull soil erosion experiments to further reveal the mechanism of soil erosion.

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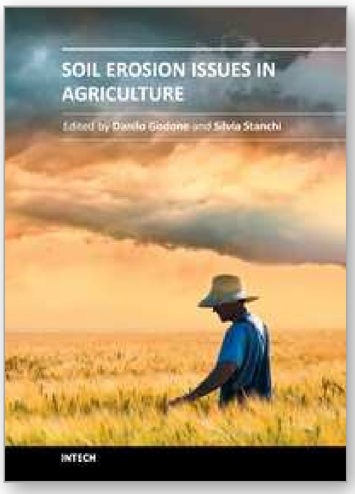

Soil Erosion Issues in Agriculture

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The book deals with several aspects of soil erosion, focusing on its connection with the agricultural world. Chaptersâ€™ topics are various, ranging from irrigation practices to soil nutrient, land use changes or tillage methodologies. The book is subdivided into fourteen chapters, sorted in four sections, grouping different facets of the topic: introductive case studies, erosion management in vineyards, soil erosion issue in dry environments, and erosion control practices. Certainly, due to the extent of the subject, the book is not a comprehensive collection of soil erosion studies, but it aims to supply a sound set of scientific works, concerning the topic. It analyzes different facets of the issue, with various methodologies, and offers a wide series of case studies, solutions, practices, or suggestions to properly face soil erosion and, moreover, may provide new ideas and starting points for future researches.