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RESEARCH ARTICLE

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Factors affecting distribution of microbiotic crusts in the grain-for-green land of the loess region, northern Shaanxi, China

Abstract A field survey was conducted in the grain-for-green land of the loess region, northern Shaanxi, China, from July to August of 2005 to provide a scientific evaluation of the grain-for-green project, including its soil and water conservation and other ecological benefits for the region. The distribution of microbiotic crusts were studied, while human disturbance, aspect, topography, vegetation structure and other factors affecting it were obtained from the analysis of survey data from 78 sample plots. Results show that crust coverage is larger on less-disturbed plots than on highly-disturbed ones, on north-facing plots than on south-facing ones and on gully-slopes than on ridge-slopes. Coverage increases with herbal coverage and trees can provide better conditions for distribution of crusts than shrubs. Therefore, crust coverage is larger in herb-dominated plots than in tree-dominated ones and crusts in shrub-dominated plots are smaller. However, we made no progress in our study on deciding how slope degrees and herb species affect the distribution of crusts. We believe that more studies are necessary for a further exploration of the relationship between them.

Keywords microbiotic crusts, distribution, factors affecting crusts, loess region

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1 Introduction

Microbiotic crusts are an important component of soil surfaces in arid and semi-arid ecosystems (West, 1990). They are aggregations of non-vascular plants (mosses, liverworts, algae, lichens, fungi, bacteria and cyanobacteria) which form intimate associations with surface soils (Eldridge and Greene, 1994). Due to their extraordinary ability to survive desiccation and extreme temperatures (up to 70°C), high pH and high salinity, microbiotic crusts have been found in desert areas all over the world and may constitute as much as 70% of the living cover of some plant communities (West, 1990). Microbiotic crusts play a vital role in ensuring proper structuring and functioning of desert ecosystems, with functions such as engagement in the process of formation, stability and soil fertility, prevention of soil erosion caused by wind or water, and support for the colonization of vascular plant and stability of sand dunes (Eldridge and Greene, 1994). Studies of these crust communities have increased considerably in recent years in different parts of the world; however, most of these studies aimed at microbiotic crusts in desert areas, leaving many other types of arid and semi-arid ecosystems poorly explored.

A number of studies have also been conducted in China, mainly concentrating on microbiotic crusts in desert areas. For example, the effect of microbiotic crusts on sand-fixing vegetation were studied in arid desert regions of the country by Li et al. (2000); effects of microbiotic crusts on dew deposition were studied in the restored vegetation area at Shapotou, in northwestern China by Liu et al. (2006) and microstructure and spatial distribution patterns of microbiotic crusts in the Gurbantunggut Desert of northern Xinjiang by Zhang et al. (2006, 2007). However, studies about microbiotic crusts on the Loess Plateau are rare. The Loess Plateau in China is one of the most intensely eroded regions around the world. Microbiotic crusts, as a special layer of soil surfaces, can dramatically enhance erosion stability of soils and reduce wind and water erosion on soil surfaces. These crusts are thus of great significance to soil and water conservation on the Loess Plateau. In our study, we attempted to explore how microbiotic crusts are distributed in the grain-for-green land of the loess region in northern Shaanxi and analyze how human disturbances, aspect, topography, slope and vegetation structures affect their distribution. Our objective was to provide a scientific basis for evaluating the grain-for-green project, including its soil and water conservation as well as other ecological benefits.

2 Study area

The study took place in Wuqi County of Shaanxi Province, China, which is located in the center of the Loess Plateau and is a typically hilly and gully loess region with an area of 3791 km^2. Wuqi County is dominated by a warm temperate continental monsoon climate with a mean annual temperature of 7.8°C. The mean annual precipitation is 483.4 mm, falling predominantly from July to September. During that period precipitation can amount up to 301.7 mm, accounting for 62.4% of the average total amount. Precipitation is also spatially unbalanced, decreasing from the southern part of the area to the northern part. In the south of the county the mean annual precipitation can reach around 500 mm, compared to only about 350 mm in the north. The predominant type of soil within the area is loess, covering about 97.6% of the total area. The vegetation of the area is dominated by various trees such as *Populus davidiana*, *Armeniaca sibirica*, *Robinia pseudoacacia*, *Hippophae rhamnoides*, *Pyrus betulaefolia*, *Caragana intermedia* and *Lespedeza bicolor* and herbaceous plants such as *Stipa bungeana*, *Agropyron cristatum*, *Thymus mongolicus*, *Pennisetum centrasiaticum* and *Heteropappus altaicus*. Since 1998 when the grain-for-green project was implemented, an area of 1100.47 km^2 has been converted into forests, of which about 500 km^2 was converted from cropland and about 502 km^2 from ungrazed grassland. Vegetation coverage and forest coverage rates of the county have increased from 22.4% to 49.6% and from 13.2% to 18.7% respectively. The annual soil erosion rate has fallen from 13400 t/km^2 to 8800 t/km^2, indicating a dramatic improvement in the local environment.

3 Methods

During the field survey from July to August of 2005, we adopted line transects, sample plots and quadrants as main survey approaches. First, given the natural conditions of Wuqi County such as climate and topography, we chose two line transects on the regional scale: one from the northern part of the county to the southern part and the other one from the eastern part to the western part. Second, we selected 14 typical watersheds along the line transects based on climate, topography and vegetation structure. Then, in each watershed we chose several representative longitudinal sections and used the hatches as line transects as the scale of each watershed. Further sample plots were very intensively established along the hatches, from the ridge to the middle-upper part of the slope (called the ridge-slope), to the lower part of the slope (called gully-slope), to the gully, and to the opposite side in an opposite sequence (A → B → C → D → E → F → G) (Fig. 1). Sample plots generally had an area of 20 m × 20 m except for a few plots with an area of 10 m × 10 m due to topographic restrictions or dominance by well representative trees. The total number of sample plots was 78. Finally, we marked five herbal quadrats (1 m^2 in area) at each sample plot diagonally (Fig. 2). Specifically, the intersection point of the diagonals of the plot and the midpoints on the lines between vertices and the intersection were chosen as the center points of the five herbal quadrats (Sun and Zhu, 1995). At sample plots with an area of 10 m × 10 m, the number of herbal quadrats was, accordingly, reduced to three.

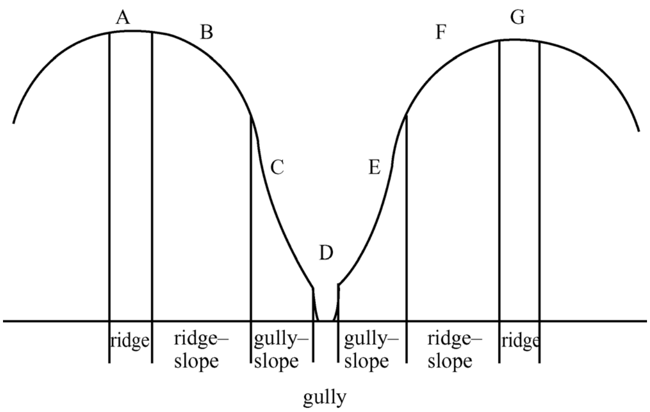

Fig. 1 Profile of sample plots along a line transect as scale of the watershed

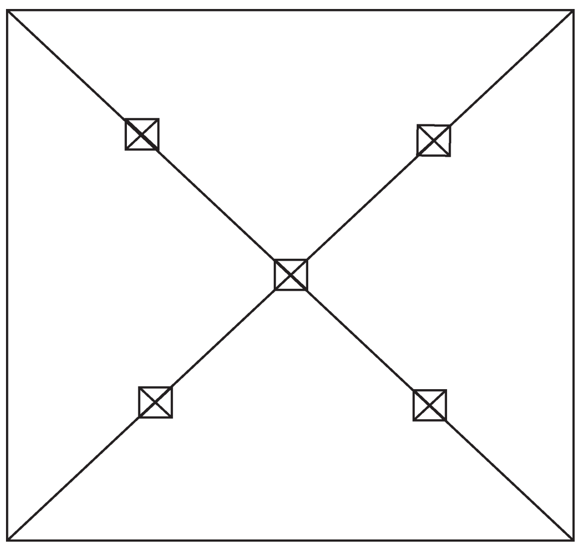

Fig. 2 Arrangement of quadrats in a sample plot

For every sample plot, we first determined its position, aspect and slope with a GPS device and a compass respectively and recorded its topographic position, vegetation structure, types of soil erosion and other characteristics. We then investigated of trees in the plot by species and number for each species, age, height, breast diameter, and crown density. We also measured shrub species by age, height and ground diameter and counted the total number. For every herbal quadrat, we estimated the total coverage of herbs and the average height, coverage and abundance of every herb species. We also measured the thickness and coverage of the litter layer and microbiotic crusts. Finally, we averaged these data to obtain an overall condition of the plot.

4 Results and analysis

The distribution and growth of microbiotic crusts are affected by many factors, including elevation, soil, aspect, water, disturbance, community structure of vascular plants and microhabitat (Ponzetti and Mccune, 2001). Therefore, we adopted a variable control method to analyze the data we collected to present the distribution of crusts more clearly. Specifically, it meant that we needed to study how one factor affected the distribution of crusts when other factors were identical or similar. We assumed that human disturbance, aspect, topography, slope and vegetation structure were main factors which affected the area. To simplify the analysis, we classified the 78 sample plots according to their aspects, topographic positions, slope degrees and vegetation structures. First, slopes were categorized into south-facing ones (22.5° east from south, south, 22.5° west from north) and north-facing ones (22.5° west from north, north, 22.5° east to south). Each slope was then divided into four parts: ridge, ridge-slope, gully-slope and gully based on the topographic characteristics of the loess region as shown in Fig. 1. Slopes were sorted into four kinds on the basis of their steepness: very-gentle slopes (< 15°), gentle slopes (15°–25°), steep slopes (25°–35°), extremely-steep slopes (> 35°). A final classification, based on the vegetation structure at a sample plot, depended on the kind of plants that dominated it: trees, shrubs or herbs.

4.1 Anthropogenic factors

In arid and semi-arid regions, disturbance is one of the main factors that can affect the formation and growth of microbiotic crusts. It has been proven that intensive and frequent disturbances will cause soils to become completely exposed (Harper and Marble, 1988). During our field survey, we found that there were several sample plots where *Medicago sativa* was cultivated. Given that *M. sativa*, as a kind of forage, needs to be regularly harvested, the plots where it grows will suffer more intensive and frequent human disturbances. We selected two plots typical of *M. sativa* and compared them with other two plots where *M. sativa* was not planted but other factors were identical or similar to the first two. Our comparison shows that crust coverage was dramatically smaller at plots with *M. sativa* decreasing to zero than those without it (Table 1). Cleary, intensive and frequent disturbance is harmful to the distribution and growth of microbiotic crusts in the grain-for-green land of the loess region in northern Shaanxi. Although the number of sample plots used in this comparison is insufficient for study, it proves that human disturbance is an important factor that should be taken seriously.

4.2 Effect of aspect

On unstable soils lichens and mosses only grow beneath vascular plants or on north-facing slopes because high humidity is advantageous to their growth (Ponzetti and Mccune, 2001). Microbiotic crusts form more easily on slopes facing northeast in desert regions at low elevations because temperature and humidity there are more beneficial to their development (Wu et al., 2003). To show how aspect affects the distribution of crusts in the loess region, we selected 40 sample plots and divided them into 20 groups of two plots each. The two plots of a group were different in aspect but identical or similar in other respects. The comparison shows that the crust coverage is larger on north-facing slopes than on south-facing ones, which is consistent with results obtained from previous studies (Table 2).

4.3 Effect of topographic position

To study the topographic effect on crust coverage, we chose 23 herb-dominated sample plots and divided them into eight groups. Plots in the same group were identical or similar in those factors, which potentially affect crusts. The average crust cover of each group was computed. We then compared groups where plots were in different topographic positions but otherwise identical or similar.

Table 1 Comparison of the crust coverage among plots with different disturbance intensities

vegetation structure	aspect	topographic position	slope degree	disturbance intensity	coverage of crusts/%
tree-dominated	south-facing	ridge-slope	gentle	low	25.00
				high	0.00
shrub-dominated	south-facing	ridge-slope	very gentle	low	20.00
				high	0.00

Table 2 Comparison of the crust coverage among plots at different aspects

topographic position	vegetation structure	slope degree	aspect	coverage of crusts/%
ridge-slope	tree-dominated	very gentle	south-facing	0.00
			north-facing	36.00
		gentle	south-facing	0.00
			north-facing	45.45
		steep	south-facing	0.00
			north-facing	26.67
	shrub-dominated	very gentle	south-facing	10.00
			north-facing	50.00
		gentle	south-facing	0.00
			north-facing	11.67
	herb-dominated	gentle	south-facing	25.00
			north-facing	44.50
		steep	south-facing	44.87
			north-facing	45.00
gully-slope	herb-dominated	very gentle	south-facing	78.33
			north-facing	86.67
		steep	south-facing	77.00
			north-facing	86.00
		extremely steep	south-facing	30.00
			north-facing	90.00

Results shown in Table 3 indicate that crust coverage is obviously larger on gully slopes than on ridge slopes in the grain-for-green land of the loess region. This can be attributed, to a large extent, to anthropogenic disturbances. Since gully slopes are generally steeper than ridge slopes, they suffer from fewer human activities compared with ridge-slopes and therefore have larger crust coverage.

Table 3 Comparison of the crust coverage among plots at different topographic positions

vegetation structure	aspect	slope degree	topographic position	coverage of crusts/%
herb-dominated	south-facing	steep	ridge-slope	44.87
			gully-slope	85.00
		very gentle	ridge-slope	28.33
			gully-slope	86.67
	north-facing	gentle	ridge-slope	41.20
			gully-slope	85.00
		steep	ridge-slope	37.28
			gully-slope	86.00

4.4 Slope effect

The impact of slope was studied in a slightly different way: we selected sample plots along the transect lines at the scale of the watershed and did not only consider requirements the plots needed to meet. We first chose five well-representative, longitudinal sections of watersheds and then along each hatch we selected three herb-dominated plots that were classified differently on the basis of their slope degree but were otherwise identical or similar. Comparison and analysis reveal that as the slope degree increases, the crust coverage rises along the lines except along lines 2 and 4 (Table 4). However, we are not justified in making any inferences about the effect of slope on crust coverage because their relationship is rather complex. On the one hand, disturbances are generally more intensive on gentle slopes than on steep ones so that crust coverage is generally smaller on gentle slopes. On the other hand, soil water always decreases as the slope degree increases (Jia et al., 2005), resulting in larger crust coverage on gentle slopes. Both disturbance and the amount of soil water can affect the growth and distribution of microbiotic crusts. We conclude that the effect of slope on the crust coverage is not independent of other factors and that further studies are needed to explore these relationships.

Table 4 Comparison of the crust coverage among plots at different degrees

transect line	vegetation structure	topographic position	aspect	slope degree/°	coverage of crusts/%
1	herb-dominated	ridge-slope	south-facing	19	48.33
				27	52.00
				31	69.00
2	herb-dominated	ridge-slope	south-facing	16	40.00
				22	30.00
				25	50.00
3	herb-dominated	ridge-slope	south-facing	10	28.33
				18	35.00
				32	46.67
4	herb-dominated	ridge-slope	north-facing	17	46.67
				27	40.00
				31	23.33
5	herb-dominated	gully-slope	north-facing	22	74.00
				33	86.00
				44	90.00

4.5 Effect of vegetation structure

When studying the effect of vegetation structure we used the same method as before. Unfortunately, we found that its effect on crust coverage was irregular. The reason might be that the multi-layer vegetation structure had a compound impact on microbiotic crusts, i.e., the effect of the tree and shrub layers was superimposed on that of the herb layer. Since the superimposition was unclear, it was difficult at the time to conclude any relationship between vegetation structure and microbiotic crusts. Thus, we decided to take two steps to solve this problem and make the relationship clear. First, we studied the effect of the herb layer on microbiotic crusts, for herbs compete directly with microbiotic crusts for sunshine and water. Compared with the herb layer, the tree and shrub layers affect microbiotic crusts less directly. We will discuss these later when we move to the second step where we combine them with the herb layer and analyze their effects on microbiotic crusts.

4.5.1 Effect of herb layer

We began to study how the herbal coverage affected crust coverage. We selected four plots on ridges, six on south-facing steep ridge-slopes and seven on north-facing gentle ridge-slopes, involving 46 herbal quadrats, We fitted the data from the 46 quadrats by using quadratic polynomials (Figs. 3–5). In Fig. 3 the crust coverage increases at a decreasing rate as the herbal coverage rises; the polynomial correlation coefficient is 0.901. Figs. 4 and 5 also display a positive relationship between herbal and crust coverage, although their correlation coefficients are comparatively low (0.488 and 0.691 respectively). This could be attributed to the fact that both herbs and microbiotic crusts receive more water and sunshine on ridges so that they can grow better and their relationship better displayed compared with other parts of the slopes.

We then studied the effect of the herb species on crust coverage. We used data from the six plots on south-facing steep ridge-slopes and the seven plots on north-facing gentle ridge-slopes that were already previously selected, but the number of herbal quadrats involved was reduced to 36. We fitted the data by again using quadratic polynomials. The results are shown in Figs. 6 and 7. Although we presumed that herb species have an impact on the growth and distribution of microbiotic crusts, the poor correlations makes our presumption indefensible. We believe that more sample plots and better scientific arguments would be necessary for further exploring the relationship between the herb species and crust coverage.

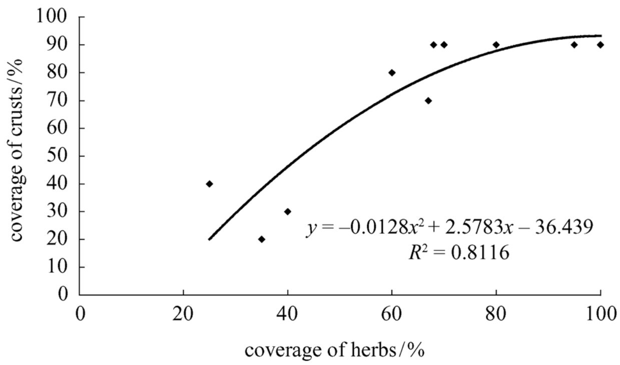

Fig. 3 Effect of herbal coverage on crust coverage on ridges

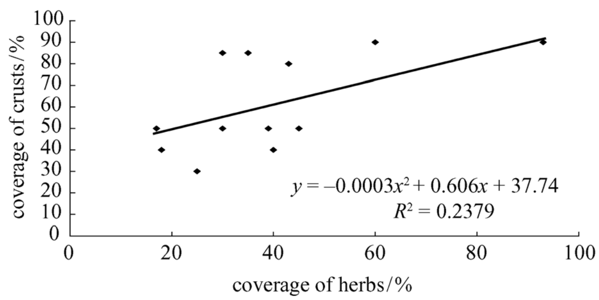

Fig. 4 Effect of herbal coverage on the crust coverage on south-facing steep ridge-slopes

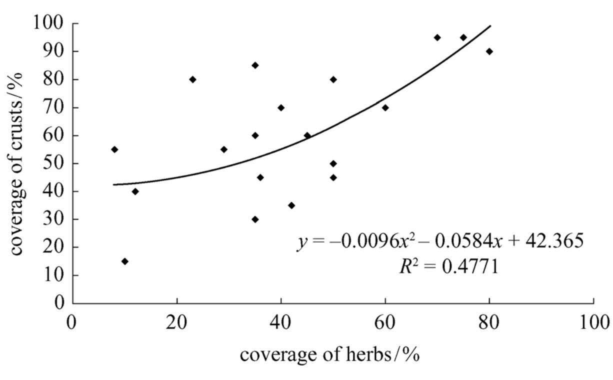

Fig. 5 Effect of herbal coverage on the crust coverage on north-facing gentle ridge-slopes

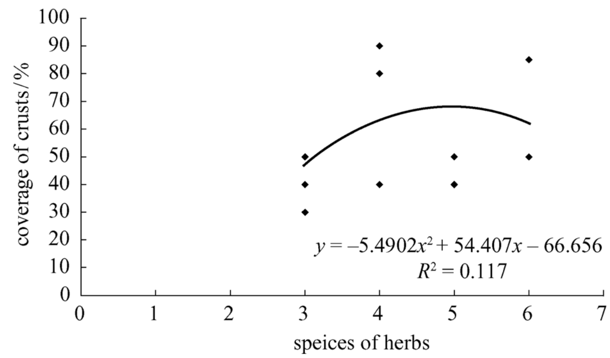

Fig. 6 Effect of herb species on crust coverage on south-facing steep

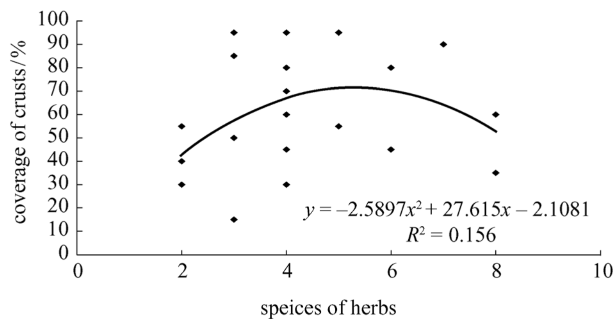

Fig. 7 Effect of herb species on crust coverage on north-facing gentle ridge slopes

4.5.2 Effect of tree and shrub layers

When we tried to superimpose the effect of tree and shrub layers on that of the herb layer, we found only a few sample plots that met the requirements of the variable control method. Since a small sample might lead to large deviations, we would rather drop this method. Instead, we grouped the plots into three based on their vegetation structure, regardless of their aspect, topography and slope. We then averaged the herbal and crust coverages of each group and compared the results among the three groups. As shown in Table 5, the crusts coverage is larger in the herb-dominated plots than in the tree-dominated ones, and the crust coverage in the shrub-dominated plots is smallest, which is consistent with the results obtained from those plots where the variable control method was adopted.

Table 5 Comparison of the crust coverage among plots with different vegetation structures

vegetation structure	amount of sample plots	coverage of herbs/%	coverage of crusts/%
tree-dominated	28	23.74	37.41
shrub-dominated	12	30.89	15.08
herb-dominated	38	50.10	43.72

Trees and shrubs compete with herbs for sunshine and water, so the herbal coverage is always smaller in tree and shrub-dominated plots than in herb-dominated plots. Because we have proven that crust coverage increases as the herbal coverage rises, crust coverage is undoubtedly larger in herb-dominated plots than in tree and shrub-dominated plots. However, crust coverage is smaller in shrub-dominated plots than in tree-dominated ones although herbal coverage there is larger. Since tree and shrub-dominated plots do not differ significantly in herbal coverage, the difference in its effect is reduced, i.e., the difference in their crust coverage is largely the result from the difference between the effects of trees and shrubs. First, in the grain-for-green land, the conditions of sites where trees are planted are always better than those for shrubs. Second, high trees offer shade and thus increase the soil moisture which is beneficial to the growth of microbiotic crusts. Finally, there is generally a thick layer of litter in tree-dominated plots which is sheltered from sunshine, intercepts precipitation and provides nutrients for microbiotic crusts. Clearly, tree-dominated areas can provide better conditions for the growth of microbiotic crusts than shrub-dominated areas and therefore crusts coverage there is larger.

5 Conclusions

During our field survey, we found that several factors such as human disturbance, aspect, topography and vegetation structure could affect the distribution of microbiotic crusts in the grain-for-green land of the loess region in northern Shaanxi. We summarized how these factors actually affected the crust distribution based on a series of analyses. First, the crust coverage is larger on less disturbed plots than on highly disturbed plots, on north-facing plots than on south-facing ones and on gully-slopes than on ridge slopes. Second, crust coverage increases as the herbal coverage rises and trees can provide better conditions for crust distributions than shrubs. Therefore, the crust coverage is larger in herb-dominated plots than in tree-dominated ones and is the smallest in shrub-dominated plots. Finally, we tried to study how the slope degrees and herb species affected the crust distribution but did not reach any definite conclusion. We believe that more studies would be necessary for further exploring these relationships.

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