Study on the degree distribution properties of soil crack

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Abstract. The Dry-hot Valley Region (DVR) is one of the typical ecologically fragile areas, but also it is a key and difficult region of vegetation rehabilitation in southwestern mountain area of China. Due to the extremely hot dry climate and strong expansion/shrinkage characteristic of soil, the cracking is a kind of extremely universal phenomenon. Soil cracking accelerates the water loss by means of evaporation, intensifying the damage of soil drought to plants, so it has become one of the important reasons for vegetation recovery. In this paper, according to complex network theory, we analyse the degree distribution properties of two typical soil-crack network in Yuanmou Dry-hot Valley Region, which includes not only the topological characteristics of the fracture network itself, but also more important study the reflected characteristics of the soil crack under different network topologies.

1. Introduction

The development of cracks is the result of soil shrinkage in arid and semiarid areas, which has a very important impact on the structure of the soil, the loss of water and solute transport in soil body and root system development [1]. Therefore, the soil crack networks have become hot points and focuses for more and more scholars [2]. Under the global climate warming and frequent occurrence of drought and flood disasters, soil drying phenomenon is becoming more and more common, Therefore, the recent advances in this field is is gradually becoming an important issue paid attention by soil science, hydrology, engineering geology and environmental science.

The Dry-hot Valley Region (DVR) is one of the regions with weak ecosystem environment, but also it is a key and difficult region of vegetation rehabilitation in southwestern mountain area of China [1,3]. In the region, the precipitation is a less and its interannual change is bigger and distribution is uneven in a year, and the amount of evaporation is larger, so water and heat are especially outstanding in this zone. By applying the complex network theory, this paper analyzed the structural complexity in two types of typical soil crack (namely vertisols and dry-red soil [4,5]) networks in DVR of Yuanmou County, that is degree distribution properties. The properties not only contain the topological property in the crack network itself, more importantly, but the characteristics revealed by soil crack under various network topological conditions shall be studied [6,7]. The crack network possesses some topological characteristics similar to other complex networks, and meanwhile it also has some outstanding features different from other complex networks. In the meantime, people gradually realize
that in order to solve problems like soil degradation and erosion mechanism, the comprehensive analysis must be conducted by taking crack network as the object [8]. Besides, as far as the tangible crack network that is under static and dynamic state concurrently is concerned, its topological structure is not constantly unchanged. It evolves continuously along with the time under the impact by external functions such as human activities or the functions formed by its mechanism. Through carrying out research in this regard, it will be helpful for us to comprehend the inherent developmental mechanism of crack network and running rules of its evolution from macroscopic to microcosmic perspective, and thus will be of great importance in revealing the dry soil and land degradation mechanism, and the revegetation practice as well in DVR [4,9,10].

2. Study area

The Yuanmou Dry-hot Valley Region is located on the lower reaches of the Longchuan River, a first-level tributary of the Jinsha River in the northern part of the Central Yunnan Plateau and is enclosed between latitudes 25°25′-26°07′N and longitudes 101°35′-102°05′E (Figure 1). It borders Wuding County in the east, Lufeng County in the south, Southwest and Great Yao and Luding County adjoin, northwest bordering with Yongren County, north and Huili County at the border.

![Fig.1. Scope of DVR in Jinsha River and location diagram of Yuanmou](image-url)
DVR of Yuanmou Country locates in downstream of Longchuan River of the first-grade tributary subordinated to Jinsha River, according to the report, the moisture content on its soil crack surface in dry season is below wilting moisture constantly and its moisture is in deficit status all the time, the plants are under severe draught, resulting in 15-20% natural vegetation coverage merely for a long time, and once its forest coverage rate was reduced to 0.06%. Although our country and the local government implemented great ecological environment construction projects centred by “planting trees and growing grass” in the name of “long-term prevention”, “long-term governance”, etc, in dry season the seedlings planted are extremely low in survival rate in numerous degraded sloping fields with deep soil layer and crack-sensitive soil body, and the revegetation construction is still under trouble situation of “invisible forest even the trees are planted every year”.

Table 1. The number of nodes and degree of two typical soil-crack-networks

| Degree | the number of nodes for the vertisols crack network | the number of nodes for the dry-red soil crack network |
|--------|-----------------------------------------------------|------------------------------------------------------|
| 1      | 631                                                 | 858                                                  |
| 3      | 1401                                                | 892                                                  |
| 4      | 17                                                  | 14                                                   |

![Fig. 2. Topology of vertisols crack network](image1)

![Fig. 3. Topology of dry-red soil crack network](image2)

There is still a certain gap between the actual and theoretical research model of soil fracture network. In order to better study the degree distribution properties of soil crack, the following assumptions are made: (1) the soil crack network is undirected network; (2) We do not consider their length and width of the edges in the networks, which their weight are 1.

The author has taken 167 vertisols and 27 dry-red soil cracks photographs, based on the typical soil crack network data in Yuanmou Dry-hot Valley Region. The two representative maps are selected (Table 1), Which their vectorization using ArcGIS software are shown in Figure 2 and 3.
3. The degree distribution analysis

Seeing from the vertisols and dry red soil networks in DVR of Yuanmou County, there are only 1, 3 and 4 nodes in the network degree, among which the number of nodes reaches to the highest in degree 3. Generally speaking, the larger the network scale (expressed by number of node), the more nodes and sides possessed by the network, that is to say, the soil crack develops in more mature way.

The node degree distribution in network \( p(k) \) refers to the probability of having exactly \( k \) sides for a node that is randomly selected [13,14]. Figure 4 shows the degree distribution for two types of soil crack networks. In this figure, the abscissa is the logarithm to node degree, the ordinate is the probability logarithm accumulated correspondingly, and the scattered points are degree distribution nodes. It is obvious that the degree distribution presents a straight line basically, which indicates the accumulative probability distribution conforms to power-law distribution roughly, and accounts for the two types of soil crack networks are free of scale. After fitting, their power exponents are \( \gamma_{\text{vertisols}} = 0.42 \) and \( \gamma_{\text{dry-red}} = 0.77 \) respectively.

![Fig. 4. Distribution diagram of node degree in two types of soil crack networks](image)

For depicting the structure of two types of soil crack networks in more detail and more completely, the features of degree correlation shall be further investigated. For the node \( i \), the average degree to all its nearby nodes is recorded as

\[
k_{\text{nn},i} = \frac{1}{k_i} \sum_{j=\text{nn}(i)} k_j
\]

In this way, the average degree to all nearby nodes with the degree of \( k \) is

\[
k_{\text{nn},k} = \frac{1}{N_k} \sum_{k_{\text{nn},i}=k} k_{\text{nn},i}
\]

The correlation between degrees is manifested by the priority connection characteristic of mutual selection between nodes. To calculate \( r \), the Pearson correlation coefficient of network node degree

\[
r = \frac{M^{-1} \sum j_i k_i - [M^{-1} \sum \frac{1}{2} (j_i + k_i)]^2}{M^{-1} \sum \frac{1}{2} (j_i^2 + k_i^2) - [M^{-1} \sum \frac{1}{2} (j_i + k_i)]^2}
\]
In this formula, \( j_i \) and \( k_i \) represent the degree of two end points on No. \( i \) side respectively, \( i=1,2,\ldots,M \), which \( M \) is the number of side to network, \(-1 \leq r \leq 1\).

From two types of soil crack networks in DVR of Yuanmou county it is found that the node degree is nothing but 1, 3 and 4, hence it is very easy to calculate the average degrees for adjacent points to all nodes, and they are \( K_{\text{vertisols}}=2.39 \) and \( K_{\text{dry-red}}=2.03 \) respectively, and their Pearson correlation coefficients are -0.526 and -0.497 respectively, which shows obvious negative correlation.

To sum up, both of the typical evolution network distributions with cracking shape in DVR of Yuanmou County could meet power-law distribution favorably [15], which indicates that they are characterized by free of scale. Meanwhile, the connotation of scale-free property is exactly the general feature in evolution of soil crack network.

Secondly, the emergence of scale-free could not be sufficiently explained by “experience” merely. The evolution of typical soil cracks in DVR is also featured by connection priority [16]. Seeing from network property, while more and more nodes are joining in, they tend to select those nodes with high degree to establish relation, such as degree 3 for increasing nodes. However, as mentioned above, due to the sides established by crack evolution network are not enough to reflect the preference relation directly, the nodes shall be combined to treat such connotation. In this way, the high degree reflects such nodes have already existed in a large number of networks, which could also be witnessed from the rest mappable units. By combining with two connotations, it could be explained as a kind of reflection of scale-free priority connection characteristic in crack evolution network [17].

4. Conclusions and future work

Through conducting research on statistical properties, degree distribution, average path length and clustering coefficient to the typical soil cracks in DVR of Yuanmou County, the following results have been obtained:

The higher the degree value of node, the larger amount of crack. The nodes with degree 3 in two types of typical soil cracks in DVR of Yuanmou County has the advantage of prominent network connection, which is particularly shown in vertisols crack network. Although the nodes with degree 1 in dry red soil network are more than that in vertisols, it is apparent that the nodes with degree 3 in dry red soil is approximately half less than that of vertisols. Besides, the nodes with degree 4 in vertisols are slightly more than that in dry red soil. Perhaps the soil surface is developed into crack network with degree 1 at first, then on account of the preference in node development and larger average degree, the vertisols cracks develop faster than vertisols, and its network develops to degree 3 “firstly”. However, the dry red soil crack “reacts dully”, which could be explained from the physicochemical properties in soil: the vertisols is featured by relatively more cracks, clayey and heavy texture, strong expansive-shrink property, and its organic matter contents are lower than that of dry red soil, moreover, the locations for most vertisols after development have been influenced by human activities, the internal stress and still water stress in soil change relatively fast, the internal stress is redistributed, presenting stable stage of fracture propagation [18], so that after being impacted by external forces, such as human cultivation, animals’ stepping, rain-wash, etc, the mechanism will be destroyed and confining pressure will be changed, and thus the continuous development to cracks becomes natural under the condition of broken status. Speaking of “reacting dully” towards external world, it is evident that crack development degree in dry red soil is higher. But the dry red soil is partial to be acid and its basement is unsaturated, and meanwhile there is hardly any expansive-shrink property. Despite many cracks on its surface, the soil is relatively stable, plus the erosion happens gradually, so its crack development is relatively slow.

The research results have laid favorable foundation for conducting in-depth research on soil crack, ground evaporation and the coupling effect of vegetation growth. Meanwhile, the results are of
significant theoretical and practical value for revealing soil drought and land degradation mechanism in DVR, and working out revegetation measures in accordance with local conditions as well.

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