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Research progress on the effects of soil erosion on vegetation

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ABSTRACT

The relationship between vegetation and soil erosion deserves attention due to its scientific importance and practical applications. A great deal of information is available about the mechanisms and benefits of vegetation in the control of soil erosion, but the effects of soil erosion on vegetation development and succession is poorly documented. Research shows that soil erosion is the most important driving force for the degradation of upland and mountain ecosystems. Soil erosion interferes with the process of plant community development and vegetation succession, commencing with seed formation and impacting throughout the whole growth phase and affecting seed availability, dispersal, germination and establishment, plant community structure and spatial distribution. There have been almost no studies on the effects of soil erosion on seed development and availability, of surface flows on seed movement and redistribution, and their influences on soil seed bank and on vegetation establishment and distribution. However, these effects may be the main cause of low vegetation cover in regions of high soil erosion activity and these issues need to be investigated. Moreover, soil erosion is not only a negative influence on vegetation succession and restoration, but also a driving force of plant adaptation and evolution. Consequently, we need to study the effects of soil erosion on ecological processes and on development and regulation of vegetation succession from the points of view of pedology and vegetation, plant and seed ecology, and to establish an integrated theory and technology for deriving practical solutions to soil erosion problems.

Soil erosion is a physical stress affecting vegetation development and also is controlled by the response of vegetation [1]. Soil erosion can reduce soil water holding capacity and nutrient accumulation to inhibit vegetation regeneration and succession [2,3] and depress vegetation cover and species richness [4,5], it can destroy plant roots by the mechanics of geomorphological processes and result in the reduction of root:shoot ratios and accelerate the process of reverse succession [4,6], and it can also reduce seed retention by soil, cause seed loss and lead to soil seed bank reduction [7], then affect seed germination and plant establishment [8]. Plant establishment is the most sensitive phase in vegetation succession [9], and is affected by seed viability and characteristics of the microsite in which seeds settle, and determines the probabilities of seed germination, seedling emergence and survival [10–12]. Seed germination, seedling emergence and survival are key processes of plant growth and development [13], and affect the structure of plant population and communities and the efficiency of vegetation restoration. Seed viability and microsite characteristics are also affected by soil erosion, and there is a negative relationship between seed viability and soil erosion [14], and the scouring and siltation of landscapes caused by soil erosion resulting in differences in microsite, soil nutrients and soil water characteristics are the main reasons for the variation in vegetation distribution patterns [15]. The effects of soil erosion on vegetation begin at the formation and development of the seed and runs through the whole process of plant growth through the effects on seed availability, seed redistribution, seed germination, seedling colonization, plant community structure and vegetation distribution patterns.

The relationship between vegetation and soil erosion deserves attention due to its scientific importance and practical applications. A great deal of information is available concerning the mechanisms and benefits of vegetation on soil erosion control [16], but in contrast, the effects of soil erosion on vegetation development and succession are poorly documented. Soil erosion studies have focused mainly on the removal of mineral particles, and very little research has taken into account the behavior of nutrients and organic matter losses. Seeds have more or less been ignored, even though they are the foundation stone of vegetation processes of colonization and recovery after disturbance [17], thus indirectly controlling soil erosion rates [8]. Therefore, combining the NSFC projects (40271074, 40571094 and 40771126), the related research is summarized to advocate more studies on the mechanisms

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of soil erosion in relation to vegetation restoration and vegetation distribution patterns and a sound theoretical basis for proper interference and regulation to accelerate vegetation restoration.

1. The effect of soil erosion on seed development and viability

Seeds are very important in the ecosystem, because they have the possibility to transform the bare soil surface into a vegetated environment by means of surface stabilization [18]. In the life history of plants, seed and seedling stages are particularly vulnerable to environmental conditions, and the processes occurring during these stages influence the structure of both adult populations and communities [17]. Colonization by seedlings is determined by seed availability as the viable seed quantities in certain soil layers per area. Seed availability depends initially on seed production and viability, then the primary and secondary seed depredation, and available reserves of seed in soil.

Soil erosion reduces the normal development of seed by decreasing soil nutrients and water, results in the failure of fertile embryo formation and the loss of seed viability. The plant seed viability in severe soil erosion areas is obviously lower than that in soil conservation areas. For example, seed viability increases with tussock cover and decreases with rock exposed by soil erosion in the meso scale in the mountains of central Argentina [14]. However, the relationship between soil erosion and seed production and viability have not been reported.

2. The effect of soil erosion on seed dispersal and redistribution

Dispersal, especially over long distances, may be a key factor in the survival of local populations, especially in fragmented landscapes [19,20], and determines the spatial distribution and survival of seed, and of seedling establishment [21–23]. In semi-arid environments where soils are regularly crusted, vegetation is sparse and where rainfall intensities are very high, soils are prone to generate surface runoff, and the overland flow and sediment transport can carry away any seeds that arrive to the surface of the soil and those which remain in the soil [10,11,24], then the secondary dispersal by surface wash may alter the primary seed deposition pattern considerably [25]. Soil erosion leads to the loss of seeds that arrive on the soil surface and those which remain in the soil by reducing seed retention by the leaf litter layer and the soil, thus reducing the density of the soil seed bank [7].

Seed loss caused by overland flow is affected by several factors, e.g. slope angle, surface roughness, rainfall intensity, and also affected by the shape and size of the seed itself [26]. Rainfall simulation experiments of 40 min duration at an intensity of 55 mm h^{-1} were have shown that the amount of seed loss was very low on the 22–55° slopes and the seed losses decrease with time due to the influence of the soil surface wetness and the strategies of the seed against erosion. In contrast, on the 2° pediment surfaces the seed losses increase with time because of the depth of ponding and the runoff velocity. Pediments have 40 times lower erosion rates and six times higher seed losses than slopes, and the temporal dynamics of the seed losses is very important [9]. The rainfall duration and intensity could both have important effects on the hydrological processes, and variation in rainfall intensity and duration will result in different responses [27]. Soil surface roughness also influences seed losses. Seeds deposited under shrubs are unlikely to be lost by surface wash, even under extreme rainfall conditions, while seeds deposited in the open field are not only easily lost, but also can result in seed predation, unsuccessful germination or seedling mortality [25]. Hoof prints strongly reduce the distance travelled by dispersed seeds [28], both seedling and species numbers were twice as high in these microtopographic features as they were in adjacent bare soil [29], showing that disturbance by cows aids seedling establishment. Bioengineering works such as vegetation barriers and structures installed perpendicular to the slope can trap and retain seeds effectively [30,31]. On the sediment deposits in the Mediterranean mountainous marly gullies, various plant species could develop and showed positive vegetation dynamics even in exceptionally dry years [30]. The results showed that seed removal rates are determined mainly by the seed size when they are lighter than 50 mg, seed shape influences the seed loss rates when the mass exceeds 50 mg, seeds greater than 10 mg and smaller than 50 mg have the lowest removal rates under the specific laboratory conditions (26 × 26 cm plot, 11° slope, rainfall intensity 55 mm h^{-1} and duration 25 min) and will vary with rainfall intensity, slope angle, surface roughness, etc. [26]. Seed shape is a key factor to affect secondary dispersal of seeds, and the flattest seeds remained on slopes, whereas the rounder seeds were almost always found in the mounds [28,29].

Seed loss caused by runoff and sediment movement of dispersed seed alters the primary seed dispersal and deposition pattern, leading to seed redistribution, and this determines seed spatial colonization, survival and seedling establishment, and in turn influences the spatial distribution of seedling regeneration, therefore playing an important role in vegetation succession and restoration [25,32,33]. However, investigations of the effects of soil erosion on seed loss are only just beginning, and only the seed losses by surface wash and the influence of seed size and shape, slope angle, plant canopy, bioengineering works and hoofprints on seed loss have been reported at present.

3. The effect of soil erosion on soil seed bank

In general, seeds that arrive on exposed soil surfaces either remain where they initially land, move over the surface, or move vertically through the soil column [34]. The soil seed bank is the collection of viable seeds present on or within the soil and associated litter at any given time and represents the stock of regenerative potential [35]. The soil seed bank is a vital part of plant community and an important seed resource for vegetation restoration, determines the rate and direction of vegetation restoration, and plays an important role in natural vegetation succession [36–38].

Soil seed bank research abroad has included studies on the spatial distribution of seeds in the soil [39], seed persistence in the soil [40], the similarity between soil seed bank and above-ground vegetation [41], the contribution of soil seed banks to vegetation restoration [42–45], the restoration and maintenance of genetic diversity from soil seed banks [46,47], and the effects of environmental factors [48–51], land use change [52,53], soil invertebrates [54], plant invasion [55,56] and grazing [57] on soil seed bank in different ecosystems such as forest, grassland, marsh and farmland. The studies on soil seed bank in China started in the late of 1980s. According to a search in CNKI (China National Knowledge Infrastructure), Elsevier, Springer Link, Blackwell Synergy, JSTOR, etc., investigations have included the size, composition, dynamics and distribution of the soil seed bank and its relationship with above-ground vegetation, and the effects of artificial disturbance (such as grazing, cutting, flooding, fertilizing and ploughing, etc.) and natural disturbance (biological crust, etc.) on soil seed banks of different single species (such as *Acanthopanax senticosus*, *Fraxinus mandshurica*, *Castanopsis fargesii*, *Larix principis-rupprechtii*, *Quercus liaotungensis*, *Picea aspoerata*, etc), single dominant plant communities (such as *Suaeda glauca* community, *Achnatherum splendens* community, *Sabina vulgaris* community, etc.), grasslands (such as the desert grassland in Inner Mongolia, the sandy grassland in the south edge of Hunshandake sandy land, the fenced