Effects of Several Engineering Measures on Vegetation Cover of Steep Slopes in Loess Regions and Their Mechanisms: Postprint

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Abstract

Steep slope: Taking a steep slope in the Lanzhou New Area as the experimental site, this study analyzed the vegetation coverage characteristics of four microtopographies (large circular pits, small circular pits, strip pits, and original slope surface) formed after artificial site preparation in the initial stage of vegetation reconstruction, and investigated the effects of environmental factors (soil hardness and moisture, surface and air temperature, slope position, non-woven fabric) on vegetation coverage, aiming to identify effective engineering measures for improving vegetation coverage. The results show that: 1. Vegetation coverage on slopes covered with non-woven fabric was significantly higher than that on control slopes; vegetation coverage at different slope positions on steep slopes followed the pattern of lower slope position > middle slope position > upper slope position ($P<0.05$), consistent with the distribution pattern of vegetation coverage on natural slopes. 2. Vegetation coverage in all three microtopographies was significantly greater than that on steep slopes, with strip pits exhibiting the highest soil moisture and vegetation coverage, and maintaining maximum coverage for the longest duration. 3. Vegetation coverage in both microtopographies and slopes was significantly positively correlated with soil moisture, and significantly negatively correlated with air temperature and surface temperature; soil hardness in microtopographies (3 kg · cm-2) was suitable for plant growth, while values exceeding this threshold inhibited vegetation growth; laying non-woven fabric promoted vegetation growth at upper slope positions and resulted in more uniform vegetation distribution across slopes. The findings indicate that when slope gradient, slope position, and temperature of steep slopes cannot be modified, implementing effective engineering measures such as tillage and site preparation treatment on compacted slopes, increasing the number of strip pits, and laying non-woven fabric can significantly increase vegetation coverage and promote vegetation restoration.

Full Text

Preamble

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Abstract: In this study, a section of steep slope in Lanzhou New Area was taken as the experimental site to analyze the characteristics of vegetation coverage over four kinds of micro-topography (long pit, small circular pit, large circular pit, and original slope) formed after artificial land preparation at the early stage of vegetation reconstruction. Moreover, the environmental factors affecting vegetation coverage, including soil hardness, soil moisture content, surface temperature, air temperature, slope position, and slope covered with nonwovens, were also analyzed so as to look for several engineering measures to effectively improve vegetation coverage. The results showed that: The vegetation coverage on the slope covered with nonwovens was significantly higher than that on the control slope, and the vegetation coverage at different positions of steep slope was in an order of lower slope > middle slope > upper slope, which was consistent with the distribution of vegetation coverage on natural slope. The vegetation coverage over three kinds of micro-topography was significantly higher than that on the steep slopes, in which the vegetation coverage, soil moisture content, and duration of maximum vegetation coverage over the long pit were the highest and longest. The vegetation coverage over the micro-topography and slope was positively correlated with soil moisture content, but negatively correlated with air temperature and surface temperature. The soil hardness of micro-topography at 3 $kg \cdot cm^{-2}$ was suitable for plant growth, and it would restrict plant growth if it was higher than this value. It was conducive to the growth of vegetation on the upper slope if it was covered with nonwovens. The results revealed that, under the conditions that the slope gradient, slope position, and temperature of steep slope could not be changed, the vegetation coverage could be effectively promoted by some engineering measures, such as land preparation and tillage on compacted slope, increase of the number of long pits, and covering of nonwovens.

Keywords: steep slope; slope protection with vegetation; vegetation coverage; micro-topography; engineering measure; soil preparation; environmental factor; Loess Plateau

Methods

Experimental Design and Measurement Protocol

The study was conducted on a steep slope section in Lanzhou New Area. The experimental design incorporated four distinct micro-topographic treatments: long pits, small circular pits, large circular pits, and an original slope control. Vegetation coverage dynamics were monitored across these treatments during the early stages of vegetation reconstruction, alongside measurements of key environmental factors including soil hardness, moisture content, surface temperature, air temperature, and slope position.

Environmental Monitoring

Temperature Measurement: Air and surface temperatures were recorded using T&D TR-71U data loggers. Sensors were positioned at two heights: 1 m above ground for air temperature and 5 cm above the surface for near-ground temperature measurements. The devices had a measurement accuracy of $\pm0.3^{\circ}$C (range: -20–80°C) and $\pm0.5^{\circ}$C (range: -40—20°C and 80–110°C).

Soil Hardness: Soil hardness was measured using a Soil Hardness Test instrument (Takemura Electric Works, LYD). The device employs a 4.5 mm diameter cone probe that penetrates the soil profile, with measurements expressed in $kg \cdot cm^{-2}$. The measurement range spans 0–500 $kg \cdot cm^{-2}$ with a resolution of 0.1 $kg \cdot cm^{-2}$. Five replicate measurements were taken per plot to ensure statistical reliability.

Soil Moisture: Soil moisture content was determined through gravimetric sampling. Three random samples were collected per plot and oven-dried to calculate water content percentage.

Vegetation Coverage: Vegetation coverage was assessed using the line-intercept method within 1 m × 1 m quadrats. Four quadrats were established per treatment, with coverage recorded as the percentage of ground area occupied by plant canopy.

Statistical Analysis

Data analysis was performed using Origin 2017 and SPSS 20.0 software. Correlation analysis examined relationships between vegetation coverage and environmental factors. Significance levels were set at $P < 0.05$ and $P < 0.01$. The vegetation coverage was calculated based on the ratio of the area covered by the vertical projection of the above-ground parts of plants to the total area of the 1 m × 1 m quadrat.

Results

Vegetation Coverage Dynamics

Vegetation coverage varied significantly among micro-topographic treatments and slope positions. On the 47th day after germination, plant growth status showed marked differences [Figure 2: see original paper]. The layout of sample plots on the steep slope demonstrated systematic variation in vegetation establishment [Figure 3: see original paper].

Micro-topography Effects: Three types of micro-topography exhibited substantially higher vegetation coverage compared to the steep slope control. The long pit treatment demonstrated the highest vegetation coverage and maintained maximum coverage for the longest duration. Small circular pits and large circular pits also showed improved coverage relative to the original slope.

Slope Position Effects: Vegetation coverage distribution followed the pattern: lower slope > middle slope > upper slope, consistent with natural slope vegetation patterns. This gradient was observed across all treatments.

Nonwoven Cover Effects: Slopes covered with nonwoven fabric showed significantly enhanced vegetation coverage compared to uncovered controls, particularly beneficial for upper slope positions where environmental conditions were more severe.

Soil Physical Properties

Soil hardness and moisture content dynamics varied by treatment [Figure 5: see original paper]. Micro-topographic treatments with soil hardness around $3\ \mathrm{kg \cdot cm^{-2}}$ provided optimal conditions for plant growth. Values exceeding this threshold restricted root penetration and shoot development. Soil moisture content showed positive correlation with vegetation coverage ($r = 0.304$–0.779, $P < 0.05$), while air and surface temperatures exhibited negative correlations ($r = -0.446$ to -0.779, $P < 0.05$) .

Correlation Analysis: Statistical relationships between vegetation coverage and environmental factors revealed significant associations. Soil moisture content was the primary positive driver, whereas temperature parameters were inhibitory factors. The correlation matrix showed consistent patterns across different vegetation types and slope positions .

Discussion

Engineering Measures for Vegetation Restoration

The results demonstrate that engineering interventions can effectively promote vegetation coverage on steep slopes where natural recovery is limited by gradient, position, and temperature constraints. Key measures include:

1. **Land Preparation**: Creating micro-topography through pit excavation (long pits, circular pits) increases surface roughness, enhancing water infiltration and reducing runoff. Long pits proved most effective, providing favorable microenvironments for seedling establishment.
2. **Soil Tillage**: Reducing soil hardness to approximately 3 $kg \cdot cm^{-2}$ through mechanical loosening alleviates compaction, facilitating root growth and water movement. This is particularly critical on construction-disturbed slopes where compaction exceeds natural levels.
3. **Nonwoven Cover**: Applying nonwoven fabric mulch moderates surface temperature, reduces evaporation, and creates stable moisture conditions. This measure showed pronounced benefits on upper slopes where temperature stress and water deficit are most acute.

Environmental Factor Interactions

The negative correlation between vegetation coverage and temperature parameters underscores the limiting role of thermal stress in arid zone slope restoration. Nonwoven covers mitigated this effect by reducing surface temperature fluctuations. The positive correlation with soil moisture confirms water availability as the primary determinant of vegetation success in this semi-arid region.

The observed slope position gradient (lower > middle > upper) reflects natural resource redistribution patterns, with water and nutrients accumulating at slope toes. Engineering measures that mimic these natural processes—such as creating micro-topographic depressions—can partially offset positional disadvantages.

Practical Implications

For steep slope vegetation projects in the Loess Plateau, combining micro-topographic modification with soil loosening and surface mulching offers an effective restoration strategy. Long pit configurations are recommended for maximum vegetation coverage and persistence. These measures are particularly valuable in areas where slope gradient and climate cannot be altered, providing actionable solutions for ecological restoration and erosion control.

Note: Figure translations are in progress. See original paper for figures.