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Effects of Self-Repair of Bending Damage on Root-Soil Reinforcement of Caragana microphylla in Arid Mining Areas: Postprint

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Abstract

To clarify the effects of bending force damage on the mechanical properties of plant roots and their self-repair mechanisms after damage following erosion in arid mining areas, the bending mechanical properties of undamaged and self-repaired Caragana microphylla roots of 1-4 mm diameter class at straight roots and lateral root branch points were studied using an HG100 digital push-pull force gauge and a self-made portable testing machine. The results showed that: In the early growing season, the ultimate bending force of undamaged Caragana microphylla roots was positively correlated with root diameter in a power function, while bending strength was negatively correlated with root diameter in a power function; the ultimate bending force and bending strength of straight roots were both greater than those at lateral root branch points; Bending force damage significantly inhibited normal root growth; after self-repair of damaged Caragana microphylla roots, the activity, growth amount, and preservation rate were all lower than those of the parallel control; both root diameter and root type were important factors affecting this inhibitory effect; the reduction degree of activity and preservation rate at lateral root branch points after damage was significantly greater than that of straight roots; After self-repair of damaged Caragana microphylla roots, both ultimate bending force and bending strength increased compared with the early growing season, but external force damage significantly hindered this increase, resulting in growth rates significantly lower than those of the parallel control; after three months, the repair rate of ultimate bending force was 48.91%, and the repair rate of bending strength was 57.59%, indicating that damaged roots did not completely lose their soil-reinforcement capacity and could gradually restore their original functions through self-repair, but the degree of self-repair was limited in the short term. The repair rate of ultimate bending force for straight roots was 60.55%, while that at lateral root branch points was only 36.34%, indicating that

under the same external load conditions, damaged straight roots of Caragana microphylla exhibited significantly greater self-repair capacity than lateral root branch points, conferring a stronger ability to resist future external damage.

Full Text

Effects of Self-Healing of *Caragana microphylla* on Root Soil Reinforcement in Arid Digging Areas

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Abstract: This study employed an HG100 digital push-pull tester and a self-developed experimental installation to investigate the anti-fracture mechanical properties of *Caragana microphylla* taproots (diameter 1–4 mm) and lateral roots before and after fracture injury. The objectives were to clarify the effects of fracture force injury on mechanical properties and the self-healing mechanism of plant roots following soil erosion in Shendong mining areas. The results indicated that: (1) During the early growth season, a positive power function correlation existed between root ultimate anti-fracture force and root diameter, while a negative correlation existed between anti-fracture strength and root diameter. Moreover, the ultimate anti-fracture force and strength of taproots were higher than those of lateral roots. (2) Fracture force injury significantly restricted normal root growth, and the activity, growth, and survival rate of *C. microphylla* roots after self-healing were all lower than those of the control group. Root diameter and root type were important factors affecting this restriction, with lateral roots showing more significant decreases in activity and survival rate than taproots after injury. (3) The ultimate anti-fracture force and strength of *C. microphylla* roots increased to some extent after self-healing compared with the early growth season, but this increase was restricted by external injury, and the growth rate was significantly lower than that of the control. The self-healing rates of ultimate anti-fracture force and strength after three months were 48.91% and 57.59%, respectively. In conclusion, the root system did not completely lose its soil reinforcement capability after injury; the original function could be gradually restored through self-healing capacity. The self-healing rates of taproots and lateral roots were 60.55% and 36.34%, respectively, demonstrating that the self-healing capacity of taproots was obviously higher than that of lateral roots.

Keywords: coal mining subsidence land; anti-fracture feature; *Caragana mi-*

crophylla; root injured; self-healing

1 Introduction

Soil erosion caused by coal mining activities severely damages vegetation root systems, compromising their soil reinforcement function. Understanding the self-healing capacity of roots after mechanical injury is crucial for ecological restoration in mining areas. Previous studies have established that root mechanical properties correlate with diameter and that different root types exhibit varying resistance to fracture. However, the recovery mechanisms of roots after fracture injury remain poorly understood, particularly for *Caragana microphylla*, a dominant shrub species in arid mining regions. This research investigates the anti-fracture mechanical properties and self-healing processes of *C. microphylla* roots to provide scientific guidance for vegetation restoration in subsidence areas.

2 Materials and Methods

2.1 Experimental Design

The study utilized an HG100 digital push-pull tester combined with a custom-built experimental apparatus to measure root mechanical properties. Taproots and lateral roots of *C. microphylla* with diameters ranging from 1–4 mm were selected during the early growth season. Roots were subjected to controlled fracture force injuries, and their subsequent self-healing processes were monitored over a three-month period.

2.2 Measurement Parameters

Root activity was measured using the triphenyltetrazolium chloride (TTC) method, with activity expressed as $g \cdot g^{1} \cdot h^{1}$. The self-healing rate was calculated as:

$$\text{Self-healing rate} = \frac{\text{Post-healing value}}{\text{Pre-injury value}} \times 100\%$$

Mechanical testing followed standard protocols for root tensile strength measurement. Statistical analyses were performed using Excel, SigmaPlot 12.5, and SPSS 20.0. One-way ANOVA was conducted to compare means, with LSD post-hoc tests at $= 0.05$ significance level. Pearson correlation analysis examined relationships between growth parameters and mechanical properties.

3 Results

3.1 Root Mechanical Properties Before Injury

During the early growth season, root ultimate anti-fracture force showed a positive power function correlation with root diameter, whereas anti-fracture strength exhibited a negative correlation with diameter. Taproots demonstrated significantly higher ultimate anti-fracture force and strength compared to lateral roots across all diameter classes [Figure 3: see original paper].

3.2 Effects of Fracture Injury on Root Growth

Fracture force injury significantly restricted normal root growth. The activity, growth increment, and survival rate of *C. microphylla* roots after self-healing were substantially lower than those of uninjured controls [FIGURE:4, FIGURE:5, FIGURE:6]. Root diameter and root type emerged as critical factors influencing the degree of restriction. Lateral roots experienced more pronounced reductions in activity and survival rate than taproots following injury.

3.3 Self-Healing of Root Mechanical Properties

After three months, the ultimate anti-fracture force and strength of injured roots increased compared to immediate post-injury values, but remained restricted relative to uninjured controls. The self-healing rate for ultimate anti-fracture force reached 48.91%, while strength recovery attained 57.59% [Figure 7: see original paper]. Taproot self-healing rates (60.55%) substantially exceeded those of lateral roots (36.34%), indicating superior recovery capacity in the primary root system.

3.4 Correlation Analysis

Correlation analysis revealed significant negative relationships between root anti-fracture force and diameter increment after self-healing ($P < 0.01$). Positive correlations existed between pre-injury mechanical properties and post-healing recovery rates . The activity of lateral roots showed stronger correlations with mechanical recovery than that of taproots.

4 Discussion

The study demonstrates that *C. microphylla* root systems retain partial soil reinforcement capability after fracture injury, with function gradually restored through self-healing processes. The superior self-healing capacity of taproots (60.55%) compared to lateral roots (36.34%) reflects differential resource allocation and structural importance within the root architecture. This differential recovery has significant implications for slope stabilization in mining areas, as taproots provide primary anchorage while lateral roots contribute to surface soil reinforcement.

The observed negative correlation between anti-fracture strength and root diameter aligns with previous research on size-dependent mechanical properties in plant tissues. The restriction of growth and mechanical recovery by injury severity suggests that multiple fracture events may compromise long-term root system effectiveness. Management strategies in mining restoration should therefore minimize root damage during critical growth periods to maintain optimal soil reinforcement function.

5 Conclusion

The root system of *C. microphylla* does not completely lose its soil reinforcement capability after injury. Original mechanical function can be gradually restored through self-healing capacity, with taproots showing significantly higher recovery rates than lateral roots. These findings provide a scientific basis for vegetation restoration and ecological management in coal mining subsidence areas, emphasizing the importance of protecting primary root structures during mining operations and restoration activities.

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