

Performance Trends of Unpaved Roads Stabilized with Woven Geotextile

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ABSTRACT: Unpaved roads, a significant portion of the global road network, often suffer from poor performance and rapid degradation due to moisture intrusion and weak soil conditions. Woven geotextiles improve soil structure by offering mechanical stabilization and promoting drainage, helping lower the water content in pavement layers. This paper discusses recent findings from performance monitoring of unpaved roads stabilized with a woven geotextile. Two full-scale test roads were constructed in Buchanan County, Iowa, as unpaved road test sections: one stabilized with the woven geotextile and a control section with no geotextile stabilization. They were installed with embedded soil moisture and temperature sensors. After construction, the test sections experienced varying precipitation and temperature conditions and real traffic loads that included passage of loaded trucks and farm equipment. The results show that the woven geotextile used effectively reduced the volumetric water content (VWC) of the subgrade compared to that of the control section. These findings underscore the potential of woven geotextiles to enhance durability and performance of unpaved roads, even under challenging environmental and traffic conditions.

KEYWORDS: Volumetric Water Content, Geotextile, Mechanical Stabilization, Unpaved Roads.

1 INTRODUCTION

Unpaved roads make up a substantial portion of the global transportation network, particularly in rural and agricultural regions. While these roads are essential for farm operations, local commerce, and access to emergency services, their long-term performance is often compromised by weak subgrade soils, moisture infiltration, and inadequate drainage, leading to rapid surface deterioration, rutting, and increased maintenance costs. Conventional maintenance techniques such as periodic grading and the addition of surface aggregates offer only short-term improvements and are not always effective or sustainable under repeated loading and wet-weather conditions.

Geosynthetics, particularly woven geotextiles, have gained attention as a viable solution for improving structural integrity and resilience of unpaved roads. Woven geotextiles act as separation, reinforcement, and filtration layers, enhancing subgrade support while minimizing water accumulation within the pavement system (Zornberg, 2017; Berg et al., 2000; Tutumluer et al., 2024). They also help preserve the integrity of the aggregate base by preventing contamination from underlying fine-grained soils (Sarma et al., 2024; Saghebfar et al., 2016). These functions are particularly valuable in regions subject to frequent freeze-thaw (F-T) cycles, where moisture-sensitive subgrades often lose strength, resulting in reduced load-bearing capacity and surface instability (Zornberg 2013, 2017). While the mechanical and hydraulic functions of woven geotextiles have been extensively demonstrated in laboratory settings (Ingle et al., 2017), there remains a significant gap in performance data from full-scale field studies. In particular, the influences of woven geotextiles on subgrade moisture retention, seasonal variation, and real traffic loading have not been fully quantified for climatic conditions of the Midwest region of the United States. Understanding how these materials behave over multiple seasons is critical for developing reliable design guidelines and encouraging broader adoption of geotextile use by local transportation agencies.

This study investigates the performance trends of unpaved roads stabilized with woven geotextiles using full-scale test sections constructed in Buchanan County, Iowa. The research efforts includes comparisons of a geotextile-stabilized section with a control section, both exposed to traffic and varying weather conditions. Through continuous monitoring of soil moisture and temperature during seasonal freeze-thaw

transitions, the study evaluates the effectiveness of woven geotextiles in improving drainage, reducing subgrade saturation, and maintaining road performance. The findings contribute to a growing body of evidence supporting geosynthetic applications in unpaved road stabilization, offering practical insights for county engineers, road maintenance planners, and infrastructure decision-makers.

2 FIELD EXPERIMENTAL PROGRAM

The test site on Frost Avenue in Buchanan County, Iowa, consisted of two 92-m long gravel road sections constructed on similar subgrade and environmental conditions to allow direct performance comparisons. One section was stabilized with a woven geotextile (WG), while the other served as a control with no geotextile stabilization. The woven geotextile was installed at the interface between the subgrade and the granular base layer to assess its impact on road performance under freeze-thaw (F-T) cycling and traffic loading. To isolate the effects of the geotextile, the construction sequencing, base thicknesses, and properties of the materials used were kept consistent across both sections. After construction, the test sections were subjected to actual traffic, including heavy trucks and agricultural equipment representative of rural roadway usage in Iowa. Figure 1 presents the typical cross-sectional layout of the two test sections. Table 2 presents the mechanical properties of the woven geotextile used in this study. Table 2 summarizes the properties of the subgrade soil and base aggregate determined through laboratory testing.

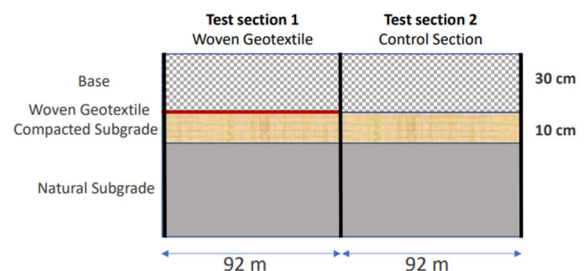


Figure 1. Cross-sectional layouts of the woven geotextile-stabilized and control test sections in Buchanan County, Iowa.

Table 1. Mechanical properties of the woven geotextile used

Mechanical Properties	Test method	Unit	Value	
Tensile Strength (at 2% strain)	ASTM D4595	kN/m	MD	CD
			7	26.3
Tensile Strength (at 5% strain)	ASTM D4595	kN/m	21	63.9
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	Maximum Roll Value	
			40 (0.425)	
Hydraulic Flow Rate	ASTM D4491	l/min/m ²	Minimum average roll value	
			3,056	
Permittivity	ASTM D4491	sec ⁻¹	Minimum average roll value	
			1	
UV Resistance (at 500 hours)	ASTM D4355	% strength retained	Minimum Test Value	
			90	

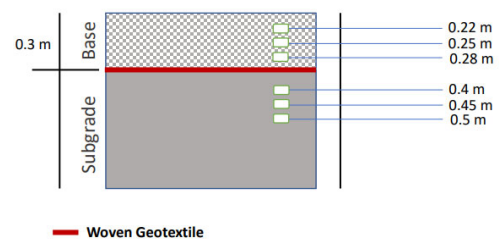
Table 2. Subgrade soil and base aggregate properties

No.	Property	Value	Standard
Subgrade	Soil classification	CL	USCS
		A-6	AASHTO
	Specific gravity	2.60	ASTM D854
	Plastic limit (%)	20.9	ASTM D4318
	Liquid limit (%)	31.8	ASTM D4318
	Plasticity index (%)	10.9	ASTM D4318
	Optimum Moisture Content (OMC) (%)	15.5	ASTM D698
	Maximum Dry Density (MDD) (KN/m ³)	17.3	ASTM D698
	Unsoaked California Bearing Ratio (CBR)%	2-3	ASTM D1883
	Base aggregate classification	GW	USCS
Base aggregate	Top size aggregate (mm)	19	AASHTO
	Percent passing the No.200 sieve (%)	10	AASHTO
	Optimum Moisture Content (OMC) (%)	4.7	ASTM D698
	Maximum Dry Density (MDD) (KN/m ³)	21	ASTM D698

Figure 2(a) illustrates the 2024 installation of the woven geotextile in Buchanan County, Iowa. The subgrade was constructed by compacting the soil in two equal lifts, each lift 5 cm thick, at the optimum moisture content given in Table 2. After the subgrade was properly prepared, the woven geotextile was installed at the subgrade–base interface. A 30-cm thick granular base was then placed in three 10-cm lifts and compacted to the required density. To capture seasonal variations in soil moisture and temperature above and below the woven geotextile, sensors were installed at multiple depths within the subgrade and base layers, as shown in Figure 2(b-d). Each test section was instrumented with six sensors connected to a data logger that recorded data continuously at 5-minute intervals, 24 hours a day, throughout the monitoring period.



(a)



(b)



(c)



(d)

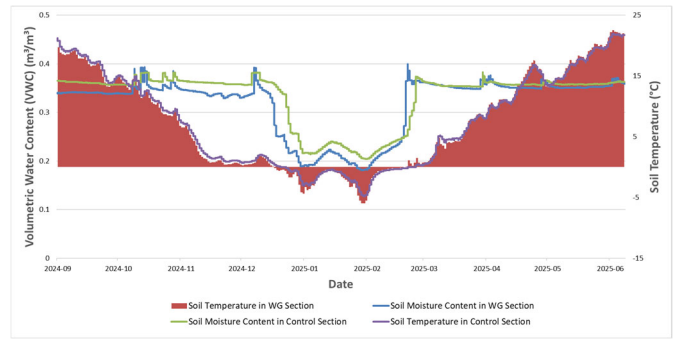
Figure 2. Field construction details: (a) woven geotextile installation, (b) moisture/temperature sensor layout, (c) installation of sensors in subgrade, and (d) installation of sensors in base layer

3 FIELD PERFORMANCE MONITORING RESULTS

3.1 Volumetric Water Content (VWC) Trends

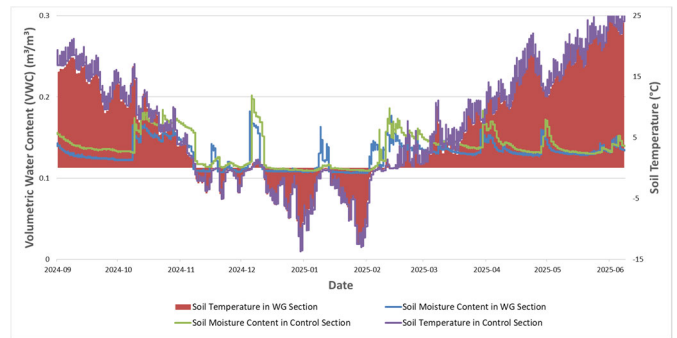
Figure 3(a-c) presents the time series of volumetric water content (VWC) and soil temperature in the subgrade for both the WG and control sections from September 2024 to June 2025. Both sections begin with relatively high VWC in September, followed by a gradual decline during the fall, with the WG section drying more rapidly, indicating enhanced drainage due to the geotextile. During the freezing period (Dec 2024–Feb 2025), both sections show sharp drops in VWC, with a more pronounced and sustained decrease in the WG section, suggesting more effective water migration or ice exclusion. As temperatures rise in the spring (Mar–Jun 2025), both sections regain moisture; but the WG section consistently maintains slightly lower VWC, an indication of its improved drainage and moisture regulation.

Figure 4(a-c) shows VWC and soil temperature trends in the base layer over the same period. Seasonal moisture variation is evident, with higher values in the fall, drying into winter, and rewetting in spring. The WG section exhibited slightly lower initial VWC in the fall, and faster drying throughout the season. During the winter months, both sections experienced low VWC values, but the WG section maintained consistently lower values, indicating better drainage prior to freezing. In spring (Mar–May 2025), the WG section showed sharper and shorter-lived moisture spikes compared to the control that retained higher moisture for longer periods. These patterns confirm the hydrological benefits of a woven geotextile, which include an improved drainage, reduced moisture retention, and a quicker seasonal response.

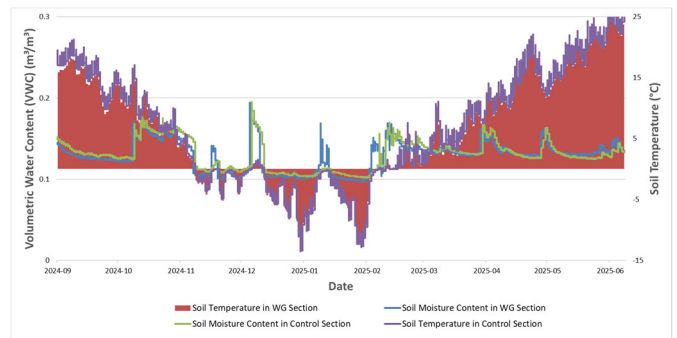


(c)

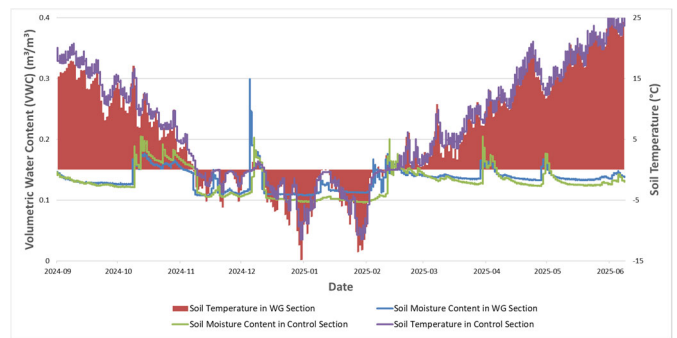
Figure 3. VWC and temperature changes in the WG section at elevations: (a) 0.40 m, (b) 0.45 m, and (c) 0.50 m below the WG compared to the values observed in the Control section



(a)



(b)



(c)

Figure 4. VWC and temperature changes in the WG section at the elevations of: (a) 0.23 m, (b) 0.25 m, and (c) 0.28 m above the WG compared to the values observed in the Control section

3.2 Temperature Effects on Woven Geotextile Performance

The soil temperature trends in the WG, and control sections generally followed similar seasonal patterns; however, key differences emerged during freeze–thaw transitions. The WG section exhibited slightly more fluctuating temperature responses, particularly during the onset and conclusion of freezing periods.

As temperatures dropped below freezing (Nov 2024–Feb 2025), the WG section showed a more rapid decline in VWC in the subgrade compared to that in the control section, suggesting that the geotextile facilitated pre-freeze drainage, reducing the potential for ice lens formation. During early spring, the WG section also demonstrated trends of quick recovery in both temperature and moisture content, indicating earlier soil thaw and rewetting. In contrast, the control section retained moisture longer, likely due to slower warming and greater moisture entrapment. These trends suggest that woven geotextiles can mitigate freeze–thaw impacts by enhancing drainage, reducing frost heave potential, and accelerating structural recovery. This behavior is consistent with previous findings on geosynthetic stabilization, where drainage and separation functions help maintain the integrity of unbound layers under extreme climatic conditions.

In the base layer, both sections experienced subfreezing temperatures from mid-November to early March. Soil temperatures in the WG section generally tracked those in the control but exhibited slightly more variability, most likely due to lower moisture levels and altered thermal properties. The WG section's lower VWC at the freeze onset supports the hypothesis of reduced ice formation risk. During thaw, the WG section exhibited faster moisture spikes and quicker drying, indicating efficient drainage. The control section, in contrast, retained higher moisture levels for longer periods, with slower thermal response. These findings clearly demonstrate the benefits of woven geotextiles in improving base layer stability during freeze–thaw cycles, consistent with the literature.

4 CONCLUSIONS

This study presented full-scale field performance data on unpaved road sections with and without woven geotextile stabilization under real-world traffic and climate conditions, including seasonal freeze–thaw cycles. The comprehensive monitoring of volumetric water content (VWC) and soil temperature across both the subgrade soil and base layers revealed that the woven geotextile used in this study significantly improved moisture regulation and thermal response compared to the control section. In both layers, the geotextile-stabilized section consistently demonstrated lower VWC, faster drying after precipitation and thaw events, and more rapid recovery during spring. These effects are attributed to the geotextile's separation and drainage functions, which reduce water retention, limit ice formation, and promote early seasonal recovery.

The base layer exhibited enhanced thermal and hydraulic performance trends, with sharper moisture fluctuations and quicker drying observed under thawing conditions. The observed improvements in subsurface moisture and thermal behavior indicate that woven geotextiles can mitigate frost-related damage, reduce maintenance needs, and improve year-round serviceability of unpaved roads. These findings contribute to the growing body of evidence supporting geosynthetics in pavement design and provide field-based validation for incorporating woven geotextiles in unpaved road applications. The outcomes are especially relevant for rural infrastructure, where cost-effective, durable solutions are critical. Future work should explore the long-term mechanical

performance and lifecycle cost analyses of stabilized sections, as well as expand monitoring to different soil types and geosynthetic materials to inform more robust design guidelines for transportation agencies.

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