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Effectiveness of Plant Derived Biopolymer for Green Protection of Soil Against Wind Erosion

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ABSTRACT

Although vegetative stabilization protects roadsides against wind erosion while improving wildlife habitat, the soil remains vulnerable to erosion during the road construction prior to emergence of vegetation. This study evaluates the effectiveness of protection offered by lignin, an inherently biodegradable and non-toxic plant-derived biopolymer against wind erosion along with the effects of lignin on soil nutrients and vegetative cover. Calcium/sodium lignosulfonate, produced from lignin by sulfite pulping process of the wood was used in wind tunnel erosion tests on soil models. To simulate the most favorable conditions for erosion soil slopes were constructed from an oven dried soil, on which different lignin solutions were sprayed prior to testing. Threshold spraying rates corresponding to onset of wind erosion were identified for tested configurations and it was found that the main factor controlling wind erosion were spraying rates. The presence of lignin did not affect the amount of vegetative cover.

INTRODUCTION

Soil erosion, which comprises wind or water induced dislodging and transport of soil particles, occurs on cropland, and unpaved roads and roadsides during the road construction. Wind erosion can also cause impaired visibility for air and ground transportation. Uncontrolled erosion accelerates over time, thus requiring erosion control via rapid revegetation, planting of quick-growing grasses, manual placement of harvested straw and erosion control blankets, and the use of compost on embankments (Barkley, 2004). Vegetative stabilization prevents wind erosion while improving wildlife habitat and aesthetics.

Construction sites are traditionally cleared from vegetation before construction, thus exposing the unprotected soil to erosion prior to the establishment of new vegetation. In this study lignin, the main component of a plant cell wall that enhances its rigidity, is used to provide protection against wind erosion during the critical road construction period. Lignin isolated from biomass is the second most abundant natural polymer after cellulose (Ganewatta et al., 2019), and it can regenerate in natural conditions via photosynthesis, resulting in approximately 50 billion tons per year (Shen et al., 2015). Lignosulfonates, which are produced from lignin through sulfite pulping of wood, are renewable, inherently biodegradable, and non-toxic. These materials offer a sustainable alternative to synthetic polymers, making them ideally suited for protection against wind and rain erosion prior to grass germination.

Wang et al. (2005) and Wang et al. (2009) investigated sand stabilization potential of lignin extracted from straw pulp black liquor waste. Their field experiment showed that a lignin solution concentration of 2% applied at a spraying rate of 2.5 l/m^2 effectively stabilized fugitive sand dunes in an arid climate. Surdahl et al. (2005) and Woll et al. (2008) found that the lignosulfonate was effective for soil stabilization and as a dust palliative material on unpaved roads. By conducting mercury intrusion porosimetry Zhang et al. (2016) determined that the cumulative pore volume of a soil stabilized with lignin decreased compared to untreated soil. Furthermore, the lignin-based cementing materials generated in a soil matrix after curing coated and bonded the solid particles and filled the pores, resulting in effective cementation that increased erosion resistance and strength. Indeed, Bagheri et al. (2023) found that adding lignin to soil caused a significant increase in cohesion and a slight reduction of friction angle based on undrained triaxial tests. Increased unconfined compression strength (UCS) was reported for silty sand (Santoni et al. 2002), clay stabilized with lignin (Tingle and Santoni 2003, Ceylan et al. 2010), and sand stabilized with lignin, based on direct shear tests (Perić et al. 2016).

While the primary objective of this study was to demonstrate the effectiveness of lignin in protecting Kansas roadsides against wind erosion the effects of lignin on the amount of soil nutrients and percentage of vegetative cover were also evaluated. Laboratory hand penetrometer tests, laboratory-scale erosion tests, and field trials were performed on the selected soil modified by calcium/sodium lignosulfonate, which is referred to herein simply as a lignin.

MATERIALS

Sieve analysis and hydrometer tests were performed in accordance with ASTM D422-63 (2007) on the soil obtained from the K-state Olathe Horticulture Research & Extension Center in Olathe, Kansas. The grain size distribution curve of the soil is shown in Figure 1

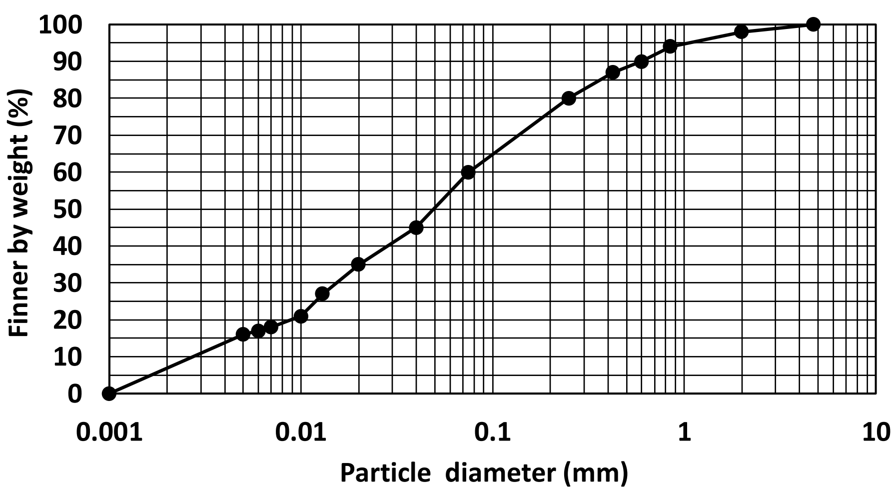

Figure 1. Grain size distribution of the soil used in this study

Atterberg limits were determined in accordance with ASTM D4318-00 (2000), resulting in the liquid limit of 32 and plastic limit of 24, and the final soil classification of a silt of low plasticity (ML) in accordance with Unified Soil Classification System (USCS).

MEHTODS

Laboratory Hand Penetrometer Tests. To simulate extreme field conditions, the soil for laboratory tests was oven dried, grinded, and placed loosely in 5.08 cm deep trays. Lignin powder was diluted in water at different concentrations and different spraying rates were used while applying the product to the soil. UCS of the soil was measured with a Gilson Soil Pocket Penetrometer HM-500, or hand penetrometer. Measurements in the laboratory were taken during a 24-hour period after spraying by pushing a penetration piston measuring 0.635 cm in diameter into the soil to a groove machined on the piston at 0.635 cm. Penetration resistance from the calibrated spring was registered on an integrated scale engraved on the penetrometer barrel. Scale units were shown, and a sliding indicator ring retained the reading until reset. An optional adapter foot attachment, available for testing very soft soils, had an increased piston diameter of 2.54 cm, which increased the contact surface area by a factor of 16. Three measurements were averaged to obtain the final reading and minimize reading errors.

Wind Erosion Tests. Similarly to hand penetrometer tests, the soil was oven dried, grinded, and deposited loosely, flush with the edge of the steel container by using a funnel bottom placed near the soil surface. This method of preparation represented the extremely favorable conditions for wind erosion. Based on the hand penetrometer test results, soil reached the post-peak strength in all wind erosion tests prior to the beginning of testing.

A container measuring 1.22 m long, 0.2 m wide, and 0.0254 m deep was filled with soil and placed within a wind tunnel constructed from a PVC frame and transparent polyvinyl fabric measuring 0.762 m wide and 0.889 m high. Wind was generated by placing a blower in front of the wind tunnel. The duration of all tests was 15 minutes. The container was inclined at 18.4° towards the horizontal direction. Three anemometers were placed near the container, and wind speed at the soil surface was obtained by averaging their measurements. The amount of eroded soil was obtained by weighing the container and soil before the beginning of the experiment and after the experiment was completed. The weight of the container was deducted from the difference, thus giving the amount of eroded soil.

Field Trial. Research trials were conducted at the K-State Olathe Horticulture Research & Extension Center during the establishment of turf grass. Plots measuring 1.52 m by 1.52 m were laid out in a randomized complete block design with four replicates (Table 1). A native grass mixture with wildflowers was seeded on June 4, 2021, at 20.4 kg of pure live seed per acre based on the recommendations of Kansas Department of Transportation (KDOT). Contents of the mixture from Sharp Brothers Seed Company (Healy, KS) included quickguard (22.4%), Sharps Improved Buffalo (18.8%), El Reno sideoats gram (15.9%), Barton western wheatgrass (8%), Aldous little bluestem (4.2%), Kaw big bluestem (4.2%), Cheyenne yellow indiangrass (4.1%), Illinois bundleflower (2.9%), blanket flower (2.1%), switchgrass blackwell (2.1%), Lovington blue grama (2%), pitcher sage (0.84%), purple prairie clover (0.81%), leadplant (0.76%), blackeyed susan (0.67%), butterfly milkweed (0.65%), lemon mint (0.63%), white prairie clover (0.6%), plains coreopsis (0.46%), maximilian sunflower (0.43%), western yarrow (0.42%), and prairie coneflower (0.41%). At the time of seeding, a 24-25-4 Scotts fertilizer was applied to the equivalent of 50.4 kg N/ha, 54.9 kg P_2O_5/ha, and 37 kg K_2O/ha.

A total of seven treatments included lignin concentrations of 1%, 2%, and 4% and were applied at the low spraying rate (1.35 l/m^2) and the high spraying rate (1.35 l/m^2) accompanied by the untreated control (Table 1). Lignin was sprayed over the soil the same day the seeding was performed while irrigation was applied the following day. This was followed by application of additional irrigation as needed to keep the soil surface moist the first few weeks after planting. The applied treatments were: 1) low volume (1.35l/m^2 and 1% lignin), 2) high volume (3.5 l/m^2 and 1% lignin), 3) low volume (1.35 l/m^2 and 2% lignin), 4) high volume (3.5 l/m^2 and 2% lignin), 5) low volume (1.35 l/m^2 and 4% lignin), 6) high volume (3.5 l/m^2 and 4% lignin), and 7) no lignin. Plot layout is depicted in Table 1.

Table 1. Plot layout for randomized complete block design

5	1	4	2	3	7	6
1	2	3	4	5	6	7
6	2	4	3	7	1	5
4	7	1	5	2	6	3

RESULTS

Figure 2 shows the development of UC strength with time based on hand penetrometer tests. Lignin content, χ_l is the ratio of mass of lignin solids and mass of soil solids. Neither the moisture content nor the lignin content of the soil was measured in this study.

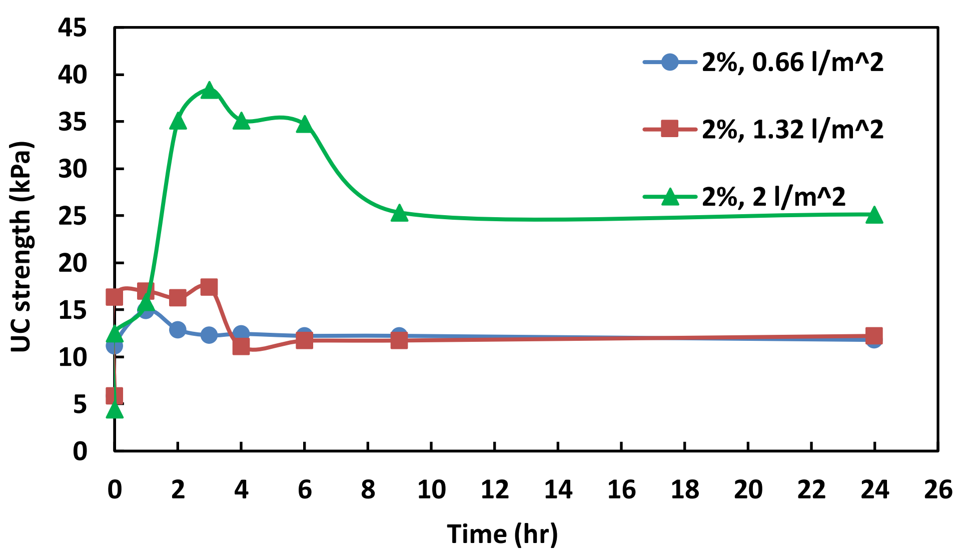

Figure 2. Development of UC strength with time based on hand penetrometer for χ_l = 2%

As shown in Figure 2, UC strength exhibits an immediate increase after spraying, resulting in the peak strength that is followed by a decrease to an early post peak strength, and a very small subsequent change during the remaining time period. Additionally, the higher the spraying rate the higher is the strength during all considered times.

Test results showing the percentage of eroded material mass versus average wind speed are depicted in Figure 3. According to the results shown in Figure 3 the amount of erosion increases nearly linearly with the wind speed. A slightly better fit with the experimental data is obtained by using a logarithmic function. The amount of erosion for unprotected soil was significantly larger than for the tested protected configurations. While higher solution concentrations at equal spraying rates offered some more protection against erosion the effect decreased as spraying rates increased and completely diminished at the rates that prevented the erosion. The erosion was completely stopped for spraying rates of 1.32 l/m^2 and higher for lignin solution concentrations of 1 and 2%. Consequently, the main factor controlling erosion appears to be the spraying rate.

Figure 4 shows the percentage of eroded soil mass versus spraying rate. The amount of erosion decays quadratically with increasing spraying rate while being larger for the larger wind speed.

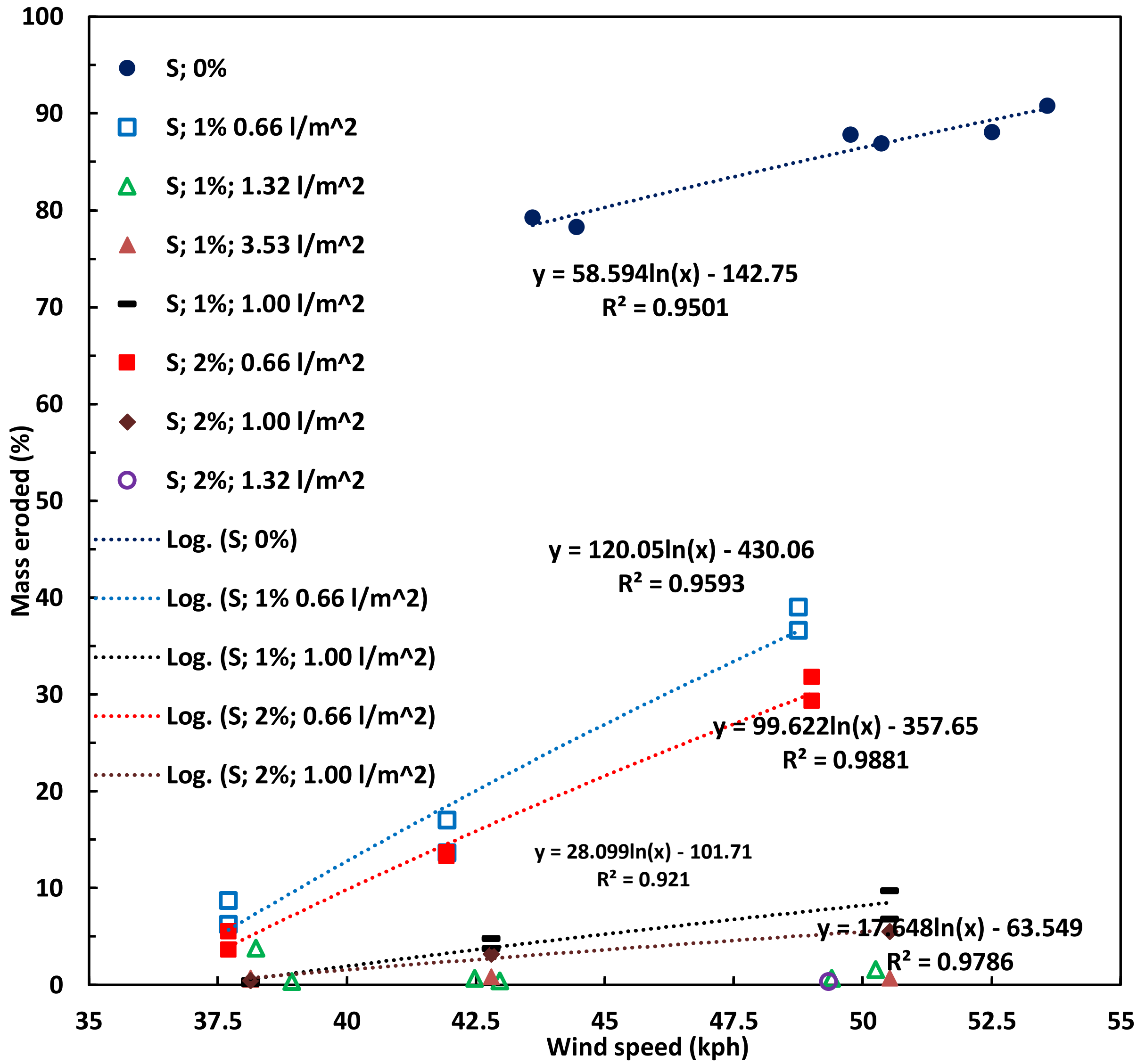

Figure 3. Percentage of mass eroded versus wind speed for different test configurations as indicated in the legend

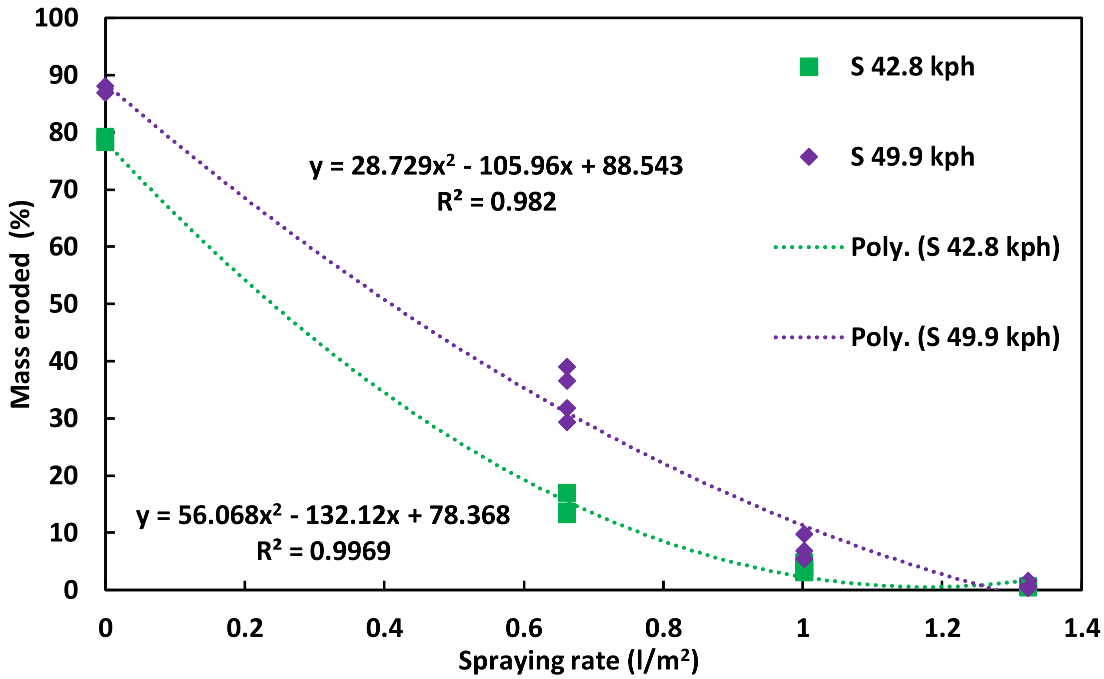

Figure 4. Percentage of mass eroded versus spraying rate for different wind speeds as indicated in the legend

The micronutrients present in the soil, such as iron (Fe) and zinc (Zn), were extracted with the chelator diethylenetriaminepentaacetic acid (DTPA) and analyzed by Flame Atomic Absorption or ICP spectrometry. Table 2 shows the measured vegetative cover and amount of iron (Fe) and zinc (Zn). All values provided in Table 2 are the average of four different measurements. The number of monocots and dicots as well as the corresponding vegetative cover indicate that presence of lignin did not affect these measurements. Soil test results indicated that the soil that received lignin at a concentration of 1% had lower Zn levels, while the soil receiving 2% lignin had lower Fe and Zn levels compared to non-treated plots. No statistically significant difference was observed for Fe and Zn levels of untreated soil and soil receiving 4% lignin solution. In spring 2022, a pre-emergence herbicide was applied to suppress annual grassy weeds, and the presence of grasses and broadleaves, including broadleaf weeds, across the plots was uniform. As shown in Table 2, means followed by the same letter are not significantly different according to Tukey's honestly significant difference (HSD) test (P < 0.05). Columns with no letters indicate no significant differences among treatments.

Table 2. Vegetative cover and amount of soil nutrients (Fe and Zn) for different field trial treatments

Treatment*	Monocots emerged (per m^2)	Dicots emerged (per m^2)	Vegetative green cover (%)	Soil Fe level (ppm)	Soil Zn level (ppm)
1% (low vol.)	538	635	41		
1% (high vol.)	215	355	41	115 a	1.8 b
2 % (low vol.)	237	86	24		
2% (high vol.)	603	237	43	98 b	1.5 b
4% (low vol.)	355	344	34		
4% (high vol.)	248	108	24	122 a	1.9 a
Untreated	506	355	33	125 a	2.0 a

*low vol. = 1.35 l/m^2; high vol. = 3.5 l/m^2

CONCLUSION

The experimental program was designed to evaluate the effectiveness of calcium/sodium lignosulfonate, herein referred to as lignin, in protecting roadsides against wind erosion. Laboratory hand penetrometer tests were conducted on oven dried low plasticity silt (ML) to evaluate strength gain versus the time elapsed since spraying the soil with a lignin solution. Moreover, erosion tests were conducted on a sloped soil configuration, inclined at 18.44° towards the horizontal direction, in a wind tunnel. In addition to these laboratory tests, a field trial on a randomized complete block was conducted to assess the effect of lignin on the amount of vegetative cover and soil nutrients.

It was found that hand penetrometer measured strength of the sprayed soil initially increased with time, thus reaching a peak value, followed by a drop and stabilization at the post peak level that remained nearly constant for the duration of the test. The higher the spraying rate, the higher the strength gain was observed.

The results of wind erosion tests show that the presence of lignin significantly decreased the amount of erosion, which in turn was primarily controlled by the spraying rate, while the lignin solution concentration had a minor effect that further decreased with increasing spraying rates. The erosion completely stopped at the spraying rate of 1.32 l/m^2 at lignin concentrations of 1 and 2% for all measured wind speeds.

The results of laboratory hand penetrometer tests and wind erosion tests agree with the previous findings in that lignin-based cementing materials generated in a soil matrix after curing coat and bond the solid particles and fill the pores, thus resulting in the effective cementation that increased erosion resistance and strength (Zhang et al. 2016).

The results of field trial showed that presence of lignin had no effect on the amount of vegetative cover while levels of Fe and Zn were lower at lignin concentrations of 1% and 2% but not at 4%. In summary, based solely on the wind erosion tests while excluding any simultaneous effects of rainfall this study shows that stabilization of near surface soil with calcium/sodium lignosulfonate can provide sufficient protection against roadside erosion during the construction period.

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