VTRC
Virginia Transportation Research Council

We Bring Innovation to Transportation

Evaluation of Rolled Erosion Control Products and Seed Mixes for Vegetation Establishment on Slopes

https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/26-R26.pdf

BRIDGET M. DONALDSON
Associate Principal Research Scientist

MARIA S. ROSSETTI, Ph.D.
Research Scientist

Final Report VTRC 26-R26

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginia.gov

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 26-R26	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Evaluation of Rolled Erosion Control Products and Seed Mixes for Vegetation Establishment on Slopes		5. Report Date: January 2026 6. Performing Organization Code:
7. Author(s): Bridget M. Donaldson and Maria S. Rossetti, Ph.D.		8. Performing Organization Report No.: VTRC 26-R26
9. Performing Organization and Address: Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 124532
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation, 1221 E. Broad Street, Richmond, VA 23219	Federal Highway Administration, 400 North 8th Street, Room 750, Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:

15. Supplementary Notes:
This is an SPR-B report

16. Abstract:

Because transportation construction projects often result in steep slopes with disturbed, bare soils that are sensitive to runoff and erosion processes, vegetation establishment is a continual challenge for transportation departments. The Virginia Department of Transportation (VDOT) regularly uses rolled erosion control products (RECPs) to mitigate erosion and provide an environment for vegetation to establish. RECPs range from erosion control blankets made of degradable natural or polymer fibers to non-degradable mats for permanent erosion protection. RECPs that promote rapid and reliable vegetation establishment help expedite environmental compliance for VDOT, a key criterion for project closeout for VDOT projects.

The purpose of this study was to (1) assess and compare the performances of RECPs in promoting vegetation establishment, (2) evaluate the performance of VDOT's basic seed mix design when supplemented with specialty seed mixes such as pollinator and strip mixes, and (3) examine the influence of air temperature, precipitation, soil temperature, and soil moisture on vegetation establishment. RECPs were installed at four VDOT project sites, and vegetation was monitored across the spring, summer, and fall seasons. Evaluations of four commonly applied RECPs and three seed mixes were conducted on geotechnically stable 2:1 slopes with varying soil types. Selected RECPS included two degradable EC-2 mats (straw-based or coconut-based soil stabilization blankets) and two EC-3 mats (non-degradable plastic matting). An image analysis program was used to determine the percentage of vegetative cover.

Results showed that degradable EC-2 mats reliably supported vegetation growth and met permanent stabilization thresholds on 2:1 slopes, with EC-2 Type 2 (jute netting and straw fiber) reaching the 75% final stabilization criterion earliest and sustaining the highest percent cover across study sites. Findings pointed to two primary reasons for the superior performance of EC-2 mats, particularly the EC-2 Type 2: (1) soil temperature results indicated that the consistently higher temperatures in EC-3 plots contributed to slower and less consistent vegetative cover relative to EC-2 plots and (2) RECP material characteristics appeared to influence vegetation establishment. EC-2 mats, and the EC-2 Type 2 mat in particular, were more flexible and conformed better to uneven or rocky slopes, whereas EC-3 mats were more rigid, prone to folding and bunching, inhibited plant emergence in some areas, and required more careful installation procedures. This report recommends that VDOT prioritize the use of EC-2 Type 2 RECPs on 2:1 slopes in place of EC-3 mats because this approach would promote faster and more reliable vegetation establishment. Because of the lower purchase cost of EC-2 Type 2 compared with EC-3 mats, VDOT would save an estimated $400,000 during a 10-year period. However, the more important benefit of using EC-2 Type 2 mats is the reduction in reseeding or permit delays. This report also recommends that VDOT continue using its updated framework for seed mix selection, which includes options for pollinator and strip specialty mixes, with selections based on specific project goals.

Supplemental materials can be found at https://library.vdot.virginia.gov/vtrc/supplements.

17. Key Words: Erosion control, soil stabilization, slopes, seeding, vegetation	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 37	22. Price:

FINAL REPORT

EVALUATION OF ROLLED EROSION CONTROL PRODUCTS AND SEED MIXES FOR VEGETATION ESTABLISHMENT ON SLOPES

Bridget M. Donaldson
Associate Principal Research Scientist

Maria S. Rossetti, Ph.D.
Research Scientist

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

January 2026
VTRC 26-R26

DISCLAIMER

The contents of this report reflect the views of the author(s), who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

ABSTRACT

Because transportation construction projects often result in steep slopes with disturbed, bare soils that are sensitive to runoff and erosion processes, vegetation establishment is a continual challenge for transportation departments. The Virginia Department of Transportation (VDOT) regularly uses rolled erosion control products (RECPs) to mitigate erosion and provide an environment for vegetation to establish. RECPs range from erosion control blankets made of degradable natural or polymer fibers to non-degradable mats for permanent erosion protection. RECPs that promote rapid and reliable vegetation establishment help expedite environmental compliance for VDOT, a key criterion for project closeout for VDOT projects.

The purpose of this study was to (1) assess and compare the performances of RECPs in promoting vegetation establishment, (2) evaluate the performance of VDOT's basic seed mix design when supplemented with specialty seed mixes such as pollinator and strip mixes, and (3) examine the influence of air temperature, precipitation, soil temperature, and soil moisture on vegetation establishment. RECPs were installed at four VDOT project sites, and vegetation was monitored across the spring, summer, and fall seasons. Evaluations of four commonly applied RECPs and three seed mixes were conducted on geotechnically stable 2:1 slopes with varying soil types. Selected RECPS included two degradable EC-2 mats (straw-based or coconut-based soil stabilization blankets) and two EC-3 mats (non-degradable plastic matting). An image analysis program was used to determine the percentage of vegetative cover.

Results showed that degradable EC-2 mats reliably supported vegetation growth and met permanent stabilization thresholds on 2:1 slopes, with EC-2 Type 2 (jute netting and straw fiber) reaching the 75% final stabilization criterion earliest and sustaining the highest percent cover across study sites. Findings pointed to two primary reasons for the superior performance of EC-2 mats, particularly the EC-2 Type 2: (1) soil temperature results indicated that the consistently higher temperatures in EC-3 plots contributed to slower and less consistent vegetative cover relative to EC-2 plots and (2) RECP material characteristics appeared to influence vegetation establishment. EC-2 mats, and the EC-2 Type 2 mat in particular, were more flexible and conformed better to uneven or rocky slopes, whereas EC-3 mats were more rigid, prone to folding and bunching, inhibited plant emergence in some areas, and required more careful installation procedures. This report recommends that VDOT prioritize the use of EC-2 Type 2 RECPs on 2:1 slopes in place of EC-3 mats because this approach would promote faster and more reliable vegetation establishment. Because of the lower purchase cost of EC-2 Type 2 compared with EC-3 mats, VDOT would save an estimated $400,000 during a 10-year period. However, the more important benefit of using EC-2 Type 2 mats is the reduction in reseeding or permit delays. This report also recommends that VDOT continue using its updated framework for seed mix selection, which includes options for pollinator and strip specialty mixes, with selections based on specific project goals.

Supplemental materials can be found at https://library.vdot.virginia.gov/vtrc/supplements.

TABLE OF CONTENTS

INTRODUCTION 1
- Rolled Erosion Control Products and Vegetation Establishment 1
- VDOT's Rolled Erosion Control Product Standards 2
- The Need for Field Evaluations 3

PURPOSE 4

METHODS 5
- Overview 5
- Information on VDOT's Hydraulic Erosion Control and Seeding Practices 5
- Study Design Creation 5
- Site Installation and Monitoring 9
- Specifying Vegetation Establishment Thresholds and Documenting Vegetative Cover 10
- Data Analysis 12

RESULTS 13
- Soil Test Results 13
- Percent Cover........ **Error! Bookmark not defined.**
- Seed Mixes 16
- Weather and Soil Variables 18
- Field Observations 20

DISCUSSION 22
- Rolled Erosion Control Product Performance 22
- Options for Selecting Higher Performing Erosion Control Products 23
- Effect of Seed Mix on Performance 23
- Additional Implications for Vegetation Establishment 24

CONCLUSIONS 24

RECOMMENDATIONS 25

IMPLEMENTATION AND BENEFITS 25
- Implementation 26
- Benefits 26

ACKNOWLEDGMENTS 28

REFERENCES 29

APPENDIX 33

FINAL REPORT

EVALUATION OF ROLLED EROSION CONTROL PRODUCTS AND SEED MIXES FOR VEGETATION ESTABLISHMENT ON SLOPES

Bridget M. Donaldson
Associate Principal Research Scientist

Maria S. Rossetti, Ph.D.
Research Scientist

INTRODUCTION

Rolled Erosion Control Products and Vegetation Establishment

The Virginia Department of Transportation (VDOT) uses rolled erosion control products (RECPs) along roadside ditches and slopes, embankments at stormwater management facilities, and as a component of other stormwater best management practices. RECPs range from erosion control blankets made of degradable natural or polymer fibers to non-degradable mats for permanent erosion protection (VDOT, 2020). These products are designed to mitigate erosion and provide an environment for vegetation to establish. The blankets or mats trap underlying soil particles and absorb the impact force of raindrops, thereby reducing soil particle loosening through the "splash" effect. RECPs also encourage infiltration by slowing stormwater runoff, which reduces soil loss and associated sediment concentrations in runoff (ASTM International, 2019). The erosion reduction capacity of an RECP varies by the slope length and gradient, soil type, and local precipitation (Bhattacharyya et al., 2010).

On steep slopes and areas with compacted soil, both of which are common to transportation projects, the material characteristics of an RECP—such as flexibility, thickness, and tensile strength—are especially important considerations. For example, any variability among RECPs with regard to the ability of the mat to conform to the ground surface may be exaggerated on steep slopes. The contact between the mat and the soil has been found to decrease as the slope gradient increases (Chen et al., 2011), which can result in water slipping through the mat fibers without infiltrating into the soil. RECPs may also vary in their effectiveness at reducing runoff in compacted soils (Álvarez-Mozos et al., 2014). Properly selected RECPs not only minimize soil erosion before vegetation is established but also support vegetation growth by helping seeds stay in place and allowing the soil to retain the moisture needed for germination.

Vegetation on slopes plays a primary role in long-term erosion protection (Ola et al., 2015). Vegetation stores precipitation in leaves and stems and promotes infiltration by increasing surface roughness and reducing soil moisture (Fullen and Booth, 2006). An RECP's role in promoting vegetation development can be a more effective runoff reduction mechanism than its physical properties (Álvarez-Mozos et al., 2014). When selecting an RECP, prioritizing its ability to promote rapid vegetation establishment under the given site and environmental conditions is therefore critical to effective erosion control and soil stabilization.

VDOT's Rolled Erosion Control Product Standards

Erosion control products used by VDOT meet the specification requirements established by the Erosion Control Technology Council and Federal Highway Administration's (FHWA) FP-03 Section 713.17 (FHWA, 2003). The Erosion Control Technology Council is an industry organization that develops standardized classifications, testing methods, and performance guidelines for erosion control products to help agencies, such as state departments of transportation, ensure consistent selection, specification, and evaluation of these materials. Table 1 lists the RECP categories from VDOT's *2020 Road and Bridge Specifications* (VDOT, 2020):

Table 1. Rolled Erosion Control Product Categories from VDOT's *2020 Road and Bridge Specifications*

Category	Type	Term	Description	Gradient
EC-2	1	Short	Single-net erosion control blanket or open weave textile composed of degradable natural or polymer fibers	Up to 1V:3H slopes and channels
	2	Short	Short-term double-net erosion control blanket composed of natural or polymer fibers	Up to 1V:2H slopes and channels
	3	Extended	Erosion control blanket or open weave textile composed of slow-degrading natural or polymer fibers	Up to 1V:1.5H slopes and channels
	4	Long	Erosion control blanket or open weave textile composed of slow-degrading natural or polymer fibers	Up to 1V:1H slopes and channels
EC-3	1	Permanent	Non-degradable mat of sufficient thickness, strength, and void space for permanent erosion protection and vegetation reinforcement	Up to 1V:1.5H slopes
	2	Permanent	Non-degradable mat of sufficient thickness, strength, and void space for permanent erosion protection and vegetation reinforcement on geotechnically stable slopes with gradients	Up to 1V:1H slopes
	3	Permanent	Non-degradable mat of sufficient thickness, strength, and void space for permanent erosion protection and vegetation reinforcement on geotechnically stable slopes	Up to 1V:1H slopes

H = horizontal; V = vertical.

Note that the slopes described in Table 1 are referred to as vertical-horizontal (V:H) ratio; a 1V:2H represents one unit of vertical rise for every two units of horizontal run. However, VDOT staff typically refer to slope gradient by the H:V ratio or run-to-rise. Throughout this report, slopes will be described by their run-to-rise ratio (for example, 2:1, which corresponds to a 26.6° incline).

EC-2 products are degradable and can be made of natural fibers such as straw, coconut, and jute. EC-3 products, often termed turf reinforcement mats, are non-degradable and fully synthetic, usually composed of thermoplastic polymers. EC-3 materials typically have stronger reinforcing action (i.e., higher tensile strength) and higher permissible shear stress (VDOT, 2020). As Table 1 indicates, as the slope gradient increases, longer term and more durable products can be selected. VDOT currently has 59 EC-2 products (divided fairly evenly across the four types) and 26 EC-3 products, 23 of which are Type III (the highest grade of EC-3), on its list of approved products (VDOT, 2025).

The Need for Field Evaluations

Seeding

Because transportation construction projects often create steep slopes with disturbed, bare soils that are highly susceptible to runoff and erosion, vegetation establishment is an ongoing challenge for VDOT. A Virginia Transportation Research Council (VTRC) study was conducted in part to address this issue (Askew et al., 2023). The study included interviews with nine District Roadside Managers (DRMs) and staff from the Location and Design Division and the Construction Division. The authors found that a primary challenge regarding seeding practices is that DRMs are not consistently consulted in the completion or approval of Roadside Development Sheets, which specify seed mixes and application rates (Askew et al., 2023). VDOT's *Maintenance Division Instructional and Informational Memorandum for Roadside Development* outlines a process by which the Location and Design Division produces a Roadside Development Sheet and "…will indicate the Maintenance Division's determination of core seed mixtures, and estimated quantities for topsoil, regular seed, temporary seed, overseeding, legume seed, fertilizer, and lime" (VDOT, 2017). In some cases, firms or contractors prepare these sheets in noncompliance with the memorandum (Askew et al., 2023). The authors recommended improving adherence to the memorandum, which places responsibility and approval authority for vegetation establishment materials and seed mixes under the purview of DRMs.

Several updates to VDOT's standards documents are underway to provide clearer guidance on seed mix design and application rates. Although VDOT standards do not mandate a single "standard" seed mix, only that certified "green-tagged" seed be used, projects are expected to follow a basic framework that emphasizes fescue species, supplemented with cover crops and legumes, and, where applicable, specialty mixes such as pollinator seeds. Updates that emphasize this framework are being incorporated into the *2020 Road and Bridge Specifications* (VDOT, 2020), an upcoming Manual of Landscape Design Guidelines, and the seeding recommendation tool, which will include expanded options for specialty seed mixes (e.g., pollinator mixes) for best management practices, wetlands, and designated pollinator areas. VDOT staff are interested in evaluating the performance of the basic seed mix design when supplemented with specialty mixes that are being applied in certain projects across the state.

Rolled Erosion Control Products

Another challenge with vegetation establishment identified by Askew et al. (2023) is the increasing use of costlier synthetic RECPs (EC-3) on VDOT projects, possibly due to the assumption that their greater material strength is more likely to satisfy regulatory requirements. This assumption has not been tested because no formal evaluations have been undertaken on the performance of RECPs on VDOT projects.

Various ASTM test methods are applicable to RECPs, including determining the erosion protection performance on slopes and their ability to encourage seed germination and vegetation growth (ASTM, 2019, 2023). However, the latter test method notes that laboratory testing should not be interpreted as indicative of field performance (ASTM, 2023). Seeding practices, soil properties, and rainfall characteristics are better represented in field conditions and can be significantly different than those in controlled laboratory environments (Smets et al., 2007).

Several studies have evaluated the field performance of RECPs regarding protection from erosion and vegetation establishment. Studies that compared the soil loss rates and vegetation establishment for RECPs made from natural (e.g., jute and coir) and synthetic fibers have mixed results. Although Álvarez-Mozos et al. (2014) found that synthetic RECPs had lower soil loss rates and better vegetation establishment than RECPs made of natural materials, Ogbobe et al. (1998) found that natural RECPs outperformed synthetic RECPs in reducing runoff volumes during early establishment. Other field-scale studies comparing RECP performance have not always reflected conditions important for transportation projects. For example, some evaluations relied on controlled methods, such as rainfall simulators, rather than field installations that account for natural environmental variation (e.g., soil types, temperature, soil moisture, site-specific rainfall events) (Benik et al., 2003; Manning et al., 2023; Rickson, 2006). VDOT would benefit from an evaluation of how factors such as vegetation establishment rates, seed mix selection, natural environmental conditions, and contractor installation practices interact to influence performance.

RECPs and seed mix design and application that promotes rapid and reliable vegetation establishment help expedite environmental compliance for departments of transportation (DOTs), an important milestone in project delivery. In Virginia, the General Virginia Pollutant Discharge Elimination System Permit for Discharges of Stormwater from Construction Activities (Virginia Department of Environmental Quality [VDEQ], 2024), commonly referred to as the Construction General Permit, enforces requirements for erosion and sediment control plans. If a project disturbs 1 acre or more of land, it must obtain coverage under the Construction General Permit (9VAC25-880). A project cannot be released from permit coverage until certain criteria are met, including permanent vegetation establishment. Closing the permit allows final payment to contractors, reduces regulatory risk (e.g., fines for noncompliance), and frees up staff and resources. To guide RECP and seed mix selection decisions and support efficient project delivery, research is needed on the field performance of RECPs commonly used for VDOT projects under site conditions representative of those found in Virginia.

PURPOSE

This study aimed to (1) assess and compare the performances of RECPs in promoting vegetation establishment, (2) evaluate the performance of VDOT's basic seed mix design when supplemented with specialty seed mixes, such as pollinator and strip mixes, and (3) examine the influence of air temperature, precipitation, soil temperature, and soil moisture on vegetation establishment. RECP installation practices and site-specific factors were also documented to consider other factors that may influence vegetation establishment.

METHODS

Overview

The study included four field installations and vegetation growth monitoring across the spring, summer, and fall seasons. Evaluations of four commonly applied EC-2 and EC-3 products were conducted on geotechnically stable 2:1 slopes with varying soil types. Statistical analyses were conducted to determine the effects of RECPs and seed mix design on vegetation establishment while accounting for confounding factors, such as air and soil temperature and precipitation.

Five tasks were conducted to fulfill the study purpose:

1. Gather information on VDOT's hydraulic erosion control and seeding practices.
2. Create the study design.
3. Install and monitor the sites.
4. Specify vegetation establishment thresholds and document the percentage of vegetative cover.
5. Analyze the data.

Information on VDOT's Hydraulic Erosion Control and Seeding Practices

To develop the study design, researchers obtained information on RECPs and seeding practices from literature and VDOT staff. Numerous documents were reviewed to gather information on RECP products, specifications, installation procedures, and seeding and nutrient requirements, including the following resources: *2020 Road and Bridge Specifications* (VDOT, 2020), VDOT's Materials Approved List (VDOT, 2023), *Road Design Manual* (VDOT, 2022), and *Drainage Manual* (VDOT, 2025). RECP installation quantity and cost information was accessed through Microsoft Power BI.

Other resources reviewed include ASTM documents on RECPs (ASTM International, 2019, 2023), the Virginia Stormwater Management Handbook (VDEQ, 2024), and the Virginia's Nutrient Management Standards and Criteria (Virginia Department of Conservation and Recreation [VDCR], 2014). Researchers held discussions with VDOT staff and contract staff experienced with vegetation establishment projects.

Study Design Creation

The study design was based on selecting RECPs, selecting seed mixes, designing study plots, and choosing sites.

Rolled Erosion Control Products Evaluated

Four types of RECPs were selected based on a review of VDOT's bid history data for RECPs (Table 2) and in consultation with the study's technical review panel. Selected RECPs were the most commonly used products approved for use on slopes with gradients 2:1 or steeper (VDOT, 2020).

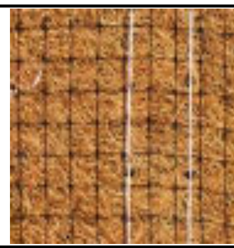
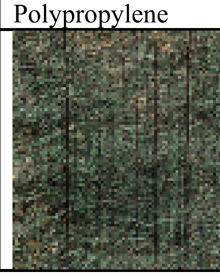
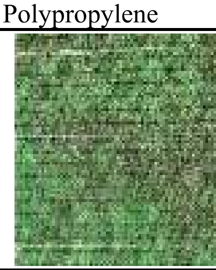
Table 2. VDOT Bid History Data (2017–2024)[a]

RECPs for 2:1 Slopes or Steeper		Number of Projects	Quantity Installed (square yards)
EC-2	Type 2	106	138,045
	Type 3	47	27,423
	Type 4	88	83,280
EC-3	Type 1	102	123,432
	Type 2	28	8,748
	Type 3	45	80,090

RECPs = rolled erosion control products. [a] Colors indicate RECPs selected for the study.

Selected RECPS included two EC-2 mats (degradable soil stabilization blankets) and two EC-3 mats (non-degradable, three-dimensional plastic matting) (VDEQ, 2024). The evaluated RECPs meet VDOT's specifications for use as soil stabilization blankets and are on VDOT's approved product list (VDOT, 2023) (Table 3).

Table 3. Descriptions of RECPs Evaluated in this Study

RECP	EC-2 Type 2	EC-2 Type 4	EC-1 Type 1	EC-3 Type 3
Netting	Double net biodegradable jute	Double net synthetic	Double net polypropylene	Double net heavy-duty polypropylene
Fiber	Straw	Coconut	Polypropylene	Polypropylene
Image *(not at an uniform scale)*				

RECPs = rolled erosion control products.

Seed Mixes Evaluated

Three seed mixes were selected in consultation with the study's technical review panel and the State Roadside Program Supervisor: a VDOT "standard" mix, a "strip mix," and a mix predominantly comprising fescues and wildflowers (referred to as "pollinator mix"). As described previously, VDOT standards do not dictate a specific seed mix, allowing site-specific flexibility. However, the seed mix tool and ongoing updates to various VDOT standards documents are based on a framework that includes fescues, cover crops (e.g., rye, millet, barley), and legumes, with specialty seed mixes available as enhancements to the standard mix where applicable. For the purposes of this study, this basic seed mix is referred to as the "standard mix." The State Roadside Program Supervisor provided seed mixes using VDOT's Roadside Development Sheet and application rate tool, which consider coverage area, slope, and season.

The standard mix in this study primarily included a blend of tall and hard fescues. The remaining species and proportions of cover crops can slightly vary by the season (Table 4). The "strip mix" also included the primary components of the standard mix (i.e., a large proportion of fescues) but was supplemented with stress-tolerant species commonly used for revegetating former strip mines (i.e., pasture and turf grass and some legumes that can persist in highly disturbed soils) (Appendix Table A1). The "pollinator mix" included the fescues that dominate the standard mix but was supplemented with a southeast annual and perennial wildflower mix. The pollinator mix was selected because a growing number of VDOT projects incorporate wildflower species that benefit monarch butterflies and other pollinators (Appendix Table A2). Seeds used for the study were green-tagged, indicating the seeds were certified for meeting VDOT's purity and germination standards.

Table 4. Primary Components of the Seed Mixes

	Standard Mix	Strip Mix	Pollinator Mix
Core Mix	(50-50 blend) Tall Fescue and Hard Fescue (85.0%)	(50-50 blend) Tall Fescue and Chewings Fescue (53.3%)	(50-50 blend) Tall Fescue and Sheep Fescue (81.6%)
Additives/Cover Crops	White Clover (4.3%)	Strip Mix (40.0%) [a]	Pollinator Mix (8.2%) [a]
	German Foxtail Millet [b] (4.3%)	German Foxtail Millet [b] (2.7%)	German Foxtail Millet [b] (6.1%)
	Annual Ryegrass (6.4%)	Annual Ryegrass (4.0%)	Annual Ryegrass (6.1%)

[a] Species list is included in the Appendix. [b] Not included at Waynesboro A site because of time of seeding.

The VDOT maintenance guidelines lists the "normal" application rate for core mix 3, a 50-50 mixture of tall and fine fescue, as 100 lb/acre and an application rate for additives (e.g., millet, ryegrass, clover) at 20 lb/acre (VDOT, 2017). However, the guidelines state that seed mixture recommendations may deviate at the discretion of DRMs. Some DRMs are now specifying 200 lb/acre to more quickly achieve permanent stability (Askew et al., 2023). For this study, the seed application rate for the standard mix and pollinator mix subplots was approximately 200 lb/acre, including the "core" mix of fescues and the additives or cover crops. The strip mix included an additional proprietary blend with an application rate of 30 lb/acre for a total application rate of 230 lb/acre.

As reflected in Table 4, the components of the seed mixes varied slightly among study sites in accordance with guidance from the warm and cool season vegetation establishment sections of the Virginia's Nutrient Management Standards and Criteria (VDCR, 2014) and associated guidance from VDOT's Nutrient Management Plan (McKinney, 2023).

Fertilizer and lime were also applied at each study site. Similar to seed mixes, the State Roadside Program Supervisor provided quantities of nutrients (fertilizer 10-10-10 and fertilizer 46-0-0) and lime using VDOT's Roadside Development Sheet and associated application rate tool. The State Roadside Program Supervisor provided seed mixes using VDOT's Roadside Development Sheet and application rate tool.

Study Plot Design and Site Selection

Figure 1 illustrates the general study design. Each RECP was 12 feet wide and divided into three 4-foot-wide subplots for seed mixes. At each site, seed mix ordering was varied so that no plot had the same sequence of seed mix treatments. The control plot represented the contractor standard practice at each site (i.e., the erosion control and seeding methods used for the rest of the VDOT project area). Control plots included either hydroseed applications or an

RECP, all which the contractor applied or installed within the same week as RECP treatment installations. At study sites where contractors applied hydroseed on the rest of the slope, 4-foot-wide buffer zones (made of leftover sections of RECPs) were installed around the RECP treatments to prevent hydroseed overspray from contaminating the RECP treatments.

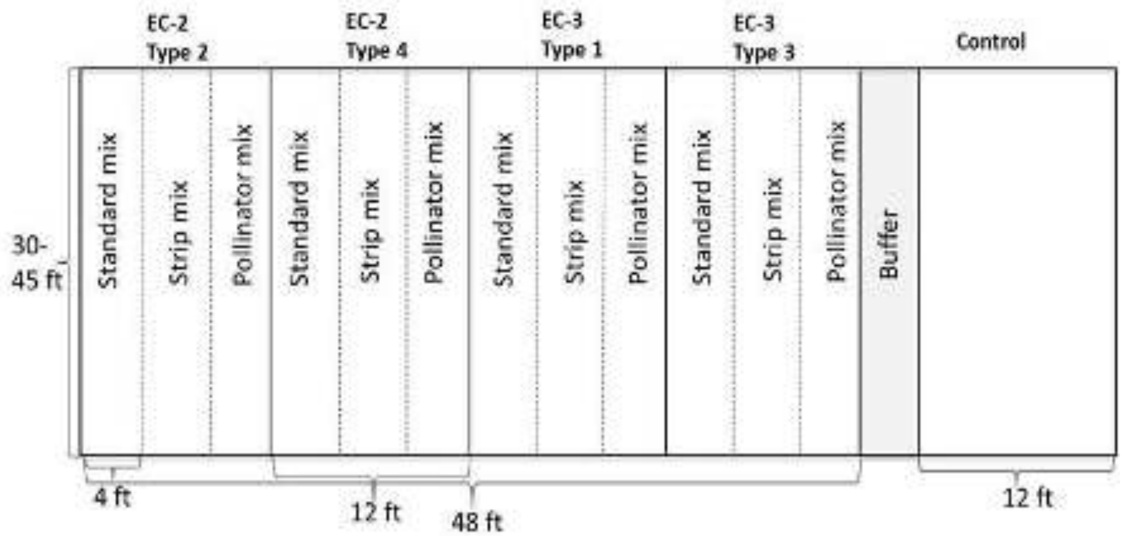


Figure 1. General Study Design

Four study sites were evaluated across three VDOT districts and with monitoring periods extending across three seasons (Table 5). All study sites were on 2:1 slopes, with RECPs extending from the top of the slope to distances of 30 to 45 feet downslope. Waynesboro sites (A and B) were 0.25 miles apart from one another and were seeded and installed in different seasons. The Waynesboro sites serve as "worst case scenarios" with regard to being cut slopes, and therefore compacted soils, and numerous small rocks. Each site was monitored until at least two RECPs achieved final stabilization (detailed in a subsequent section).

Table 5. Study Site Descriptions

Site	VDOT District	Seeding Date	Monitoring Duration	Growth Season	Slope Type	Plot Size (W x H)	Control Plot
Richmond	Richmond	6/5/2024	8 weeks	Spring/ summer	Fill	48 x 45 ft	EC-2 Type 1[a]
Waynesboro A	Staunton	9/3/2025	8 weeks	Summer/ fall	Cut	48 x 38 ft	Hydroseed
Waynesboro B	Staunton	3/19/2025	16 weeks	Spring	Cut	48 x 30 ft	Hydroseed
Wytheville	Bristol	6/9/2025	8 weeks	Spring/ summer	Fill	48 x 30 ft	Hydroseed

ft = feet; H = height; W = width. [a] EC-2 Type 1 control was comprised of jute netting and straw fiber.

At the three study sites where hydroseed served as the control plot, hydroseed applications varied in terms of type, seed mix, and application rate. Because hydroseeding was not the focus of this research, and control plots were not replicated, this report does not include the details of hydroseed applications (e.g., seed mix and application rate).

Site Installation and Monitoring

Soil Sampling, Seeding, and Rolled Erosion Control Product Installation

Prior to seeding, soil samples were collected at each study site in accordance with applicable soil sampling guidelines (VDCR, 2014). An accredited laboratory tested soil samples, which were approved under Virginia's Nutrient Management Standards and Criteria (VDCR, 2014), for soil textural class, pH, and essential elements for plant growth. Although soil tests were conducted as part of this study, they are not required for VDOT projects as long as certain requirements are met and unless initial vegetation establishment fails (McKinney, 2023).

Seeds, fertilizer, and lime were weighed and placed in labeled Ziplock bags. Prior to installation at each site, contract staff working at the project site agreed to assist with seeding and RECP installation. The researchers provided the contract field staff supervisor with the manufacturers' installation instructions for the RECPs.

Each study plot was measured and marked with flagging (Figure 2). Seeding was applied by hand, followed by hand application of fertilizer and lime. Each of these materials was applied on top of the soil. In keeping with VDOT's standard practice for fertilizer and limestone application rates when soil testing is not conducted, consistent nutrient and limestone rates were used across all study sites, irrespective of the soil pH and nutrient values obtained from the soil test results from this study. RECPs were installed over the seed and nutrients. Flagging was placed on the installed RECPs to mark the subplots and ensure that the seeded subplots remained visible from above.

Figure 2. Seeding the Marked Subplots (left) and Completed Installation of Rolled Erosion Control Products (right). The photo on the right shows buffer zones around the study plots and a marked control plot (far right) prior to the contractor hydroseeding the remaining VDOT project area.

Installation practices and any issues encountered during RECP installation were documented. Other notable observations throughout the monitoring periods were also recorded.

Monitoring Equipment

Ten CS655 soil sensors, two per RECP and two in the control plot, were used to measure soil temperature and volumetric water content, a common means of measuring soil moisture. Each plot included an upper sensor and a lower sensor, spaced approximately 20 feet apart from one another (Figure 3). Sensor cables were connected to a Campbell Scientific CR 350 data logger that stored the data.

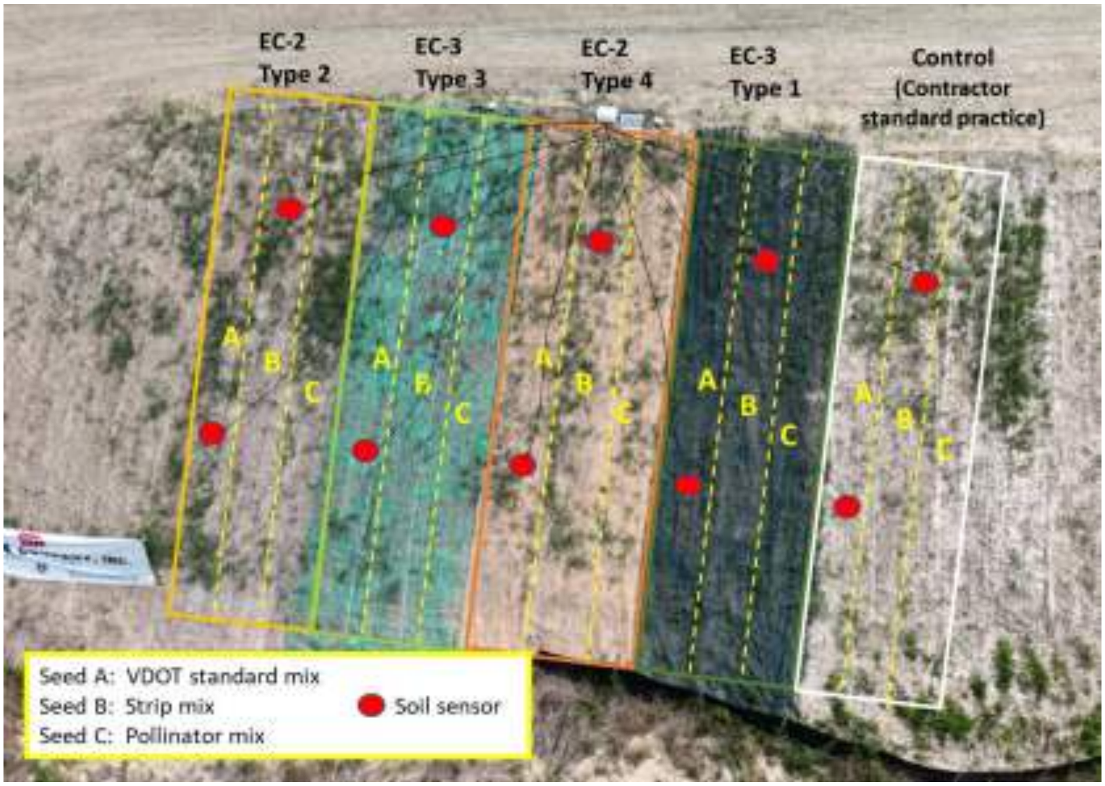


Figure 3. General Monitoring Equipment Diagram (5 Weeks after Seeding)

Weather and soil variables were monitored continuously throughout the study period. A Campbell Scientific ClimaVue^{TM} 50 weather station was used to record air temperature and precipitation. A 20-watt Campbell Scientific solar panel was used to power the monitoring equipment.

Specifying Vegetation Establishment Thresholds and Documenting Vegetative Cover

For construction activities that disturb 1 acre or more, VDOT projects can be released from stormwater permit coverage once the site meets final stabilization requirements, typically when vegetation is well established and the risk of soil erosion has been minimized. For this study, vegetation in a subplot was considered successfully established once it met the 75% final stabilization threshold outlined in the following sections from Virginia stormwater documents:

- *General Virginia Pollutant Discharge Elimination System Permit for Discharges of Stormwater from Construction Activities (9VAC25-880-1)*: Permanent vegetation shall not be considered established until a ground cover is achieved that is uniform (e.g., evenly distributed), provides 75% or more vegetative cover with no significant bare areas, is mature enough to survive, and will inhibit erosion.
- *Virginia Stormwater Management Handbook (VDEQ, 2024)*: An establishment and persistence of 75% or more living overall perennial vegetation of the intended species

mix and a maximum contiguous bare area of less than 500 square feet are required to effectively limit sheet and rill erosion and permanently stabilize the soil surface.

Digital Image Collection

To evaluate vegetative cover in each study subplot, photographs were taken at each study site approximately every 2 weeks until the 75% threshold was met in at least two of the evaluated RECPs. Images were taken using an Apple iPhone™ 13. A 3-by-4-foot frame was used to mark the area for each photo (Figure 4). Four images were taken per subplot, for 12 photos per RECP every 2 weeks.

Figure 4. Capturing Images of Vegetative Cover within a 3-by-4-Foot Frame. Four images were collected per seed mix subplot.

Digital Image Analysis

Images were analyzed using TurfAnalyzer (Karcher et al., n.d.). TurfAnalyzer selects portions of an image using a color thresholding method that selects pixels based on color properties and then determines the number of selected pixels. The program extracts the color (red, green, and blue light intensity values) and spatial (X,Y) information from each pixel in an image. Then, the program converts the red, green, and blue values to hue, saturation, and brightness values. The program user inputs a range of hue, saturation, and brightness values that are used to select green pixels. Once the green pixels are selected, the software calculates the number of green pixels and percentage of vegetative cover (hereafter referred to as "percent cover") (Karcher and Richardson, 2013).

First, images from the sites were organized into groups based on site, erosion control product, and week. Then, the images were processed in Adobe® Photoshop® version 26.1. The images were cropped using the prospective crop tool, and shadows were removed. Then, a group of processed images (e.g., EC-2 Type 2, week 2) was uploaded into TurfAnalyzer. In TurfAnalyzer, the options to "perform color analysis" and "use threshold settings (on

'Threshold' tab) to calculate average color" were selected. For each week, an image was chosen to be used to develop the threshold settings. Threshold settings were created first by selecting the built-in "Turfgrass" settings (Table 6).

Table 6. "Turfgrass" Built-in Settings

	High Value	Low Value
Hue	45	140
Saturation	10	100
Brightness	0	100

To improve the accuracy, the hue, saturation, and brightness settings were adjusted until only vegetation was visible. These settings were used to analyze a group of images. Figure 5 shows an example of an image during each phase of the image analysis process.

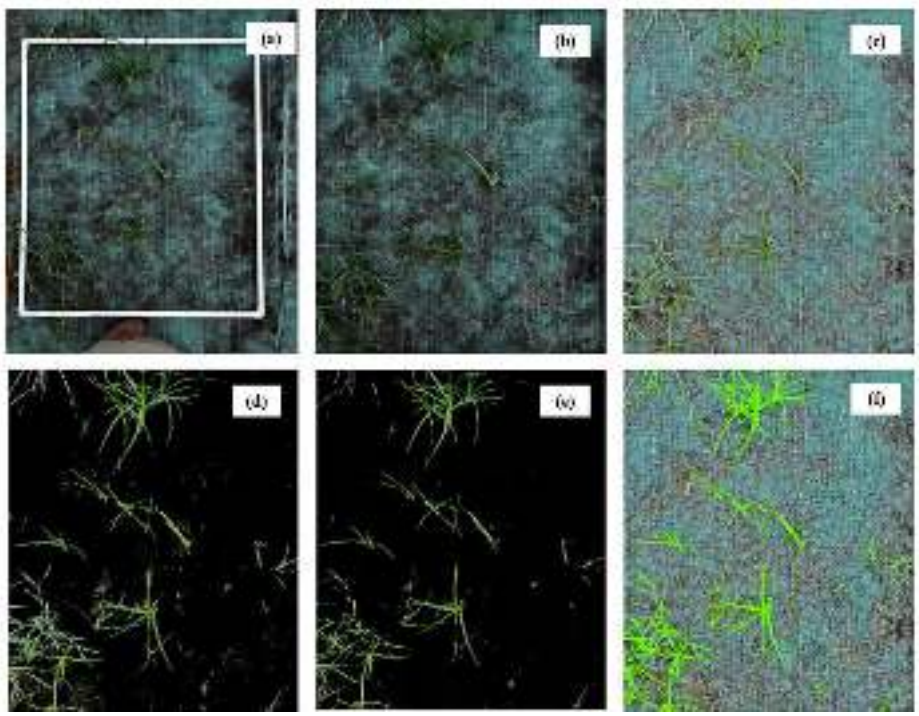


Figure 5. Example of Image Processing: (a) Original Image; (b) Prospective Cropped Image; (c) Image with Shadows Removed; (d) Image with "Turfgrass" Threshold Settings Applied; (e) Image with the Final Threshold Settings; (f) Analyzed Image. The lime green highlighted regions indicate vegetation. The example image has a 6.35% cover value.

Data Analysis

The influence of the RECP type, seed mixes, and environmental variables on the percent cover throughout the study period was evaluated. Statistical tests were conducted at the three sites where final stabilization thresholds were met (as described in a subsequent section). A one-way analysis of variance (ANOVA) was used to determine how the RECP type affected the percent cover. The same test was used to evaluate the influence of seed mix on the percent cover. Any necessary post-hoc comparisons were conducted using a Tukey's Honestly Significant

Difference test. A paired t-test was used to compare soil temperature and moisture between EC-2 and EC-3 mats taken at the same time at each site.

To assess the combined influence of RECP type and seed mix, a two-factor ANOVA was used. Post-hoc comparisons were conducted using a Tukey-adjusted pairwise comparison test. The relationship between environmental variables, RECP type, seed mix, and percent cover was determined using a Ridge Regression, a form of multiple linear regression used on highly correlated independent variables. The model was evaluated using a 10-fold cross-validation. All statistical analyses were performed in R. Information on statistical analyses that is not included in this report is available in a supplemental file.

RESULTS

Soil Test Results

Soils at the study sites were from three of the four soil divisions of Virginia soils and three different textural classes (Table 7). Soils at the Richmond and Waynesboro sites were moderately acidic, which is common to most soils in Virginia (Galbraith and Baker, 2023). Soil pH at the Wytheville site was neutral (6.6).

Table 7. Soil Division and Test Results from Study Site Soil Samples

Study Site	Soil Division	Textural Class (Sand/Silt/Clay %)	pH
Richmond	Piedmont	Sandy Loam (73/13/14)	5.2
Waynesboro (A and B)	Blue Ridge	Loam (40/3/24)	5.7
Wytheville	Appalachian	Clay Loam (27/45/28)	6.6

Soil test results from the Richmond and Waynesboro sites recommended using limestone to raise the pH to 6.5 for grass establishment. Soil test results from the Wytheville site recommended raising boron and copper levels, using borax and copper sulfate, respectively. As mentioned previously, soil tests are not typically required for VDOT revegetation projects. Application rates for fertilizer and lime were therefore the same at each site regardless of soil test results.

Percent Cover

Richmond, Waynesboro B, and Wytheville

At these three sites, the 75% final stabilization criterion was achieved in at least two RECP plots during the monitoring period. Final stabilization was not achieved in any RECP plot at the Waynesboro A site, which is discussed in a subsequent section.

Figure 6 illustrates vegetation growth at the three sites. At each of these sites, EC-2 Type 2 (jute net with straw fiber) was the first to reach the 75% final stabilization criterion. Conversely, both EC-3 mats underperformed compared with the EC-2 mats, with EC-3 Type 1 remaining below the 75% threshold at all sites and EC-3 Type 3 remaining below the threshold at two of the three sites.

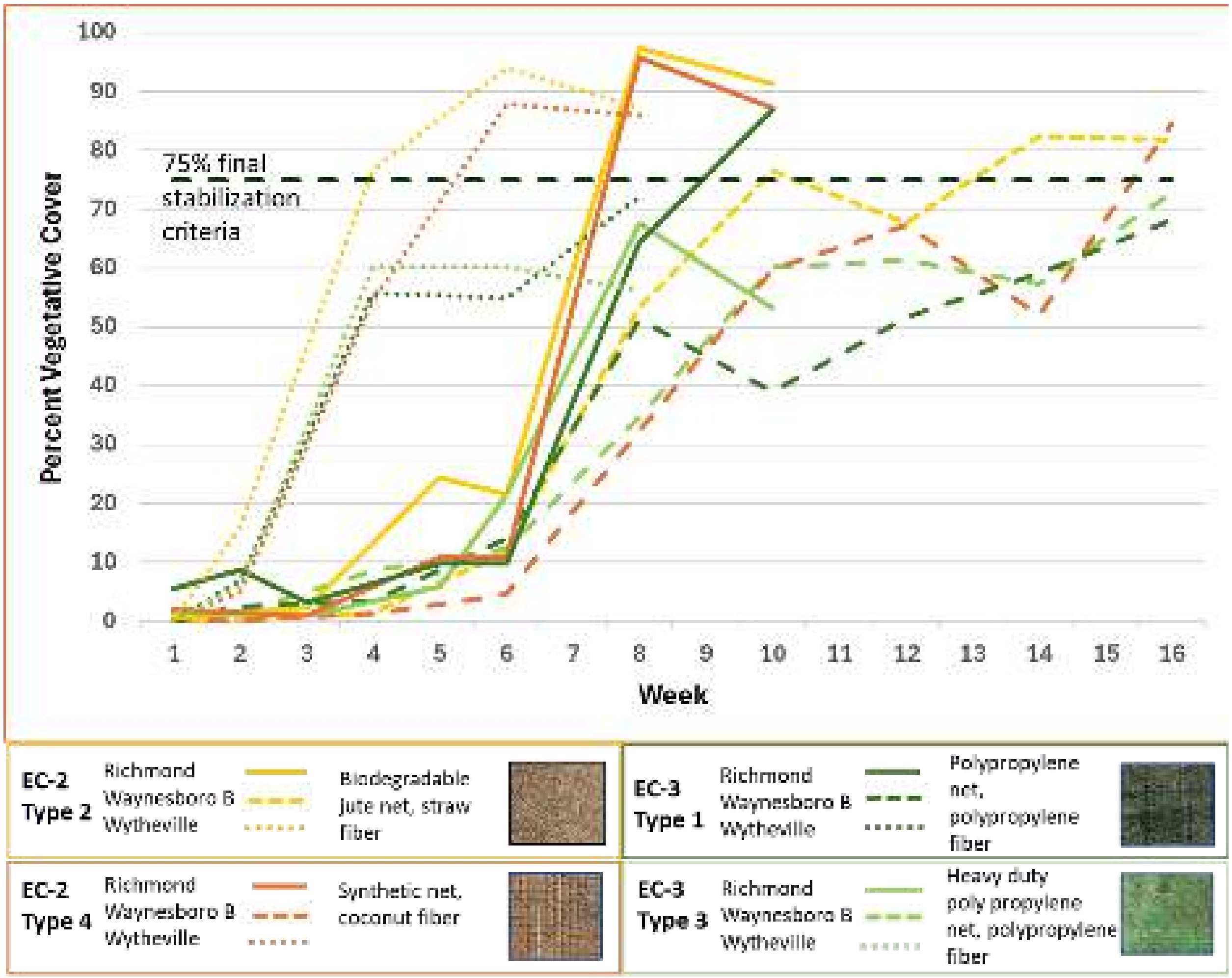


Figure 6. Percent Cover for the Standard Seed Mix at Richmond, Waynesboro B, and Wytheville Sites. Control plots are not shown.

Figure 7 includes the control plots results and illustrates the median percent cover differences. Based on the one-way ANOVA, statistically significant differences were observed among RECPs. EC-2 Type 2 plots maintained a significantly higher percent cover than both EC-3 mats at all sites and a significantly higher percent cover than EC-2 Type 4 plots at the Waynesboro B site (Tukey-adjusted $p = 0.006$). At the Wytheville and Richmond sites, the difference between the two EC-2 mats was not significant (Tukey-adjusted $p = 0.35$ and Tukey-adjusted $p = 0.926$, respectively). Of the control plots, EC-2 Type 1 (Richmond site) and the hydroseed controls reached final stabilization earlier and had higher median percent cover than most treatment RECPs. Full pairwise statistical results are included in a supplemental file.

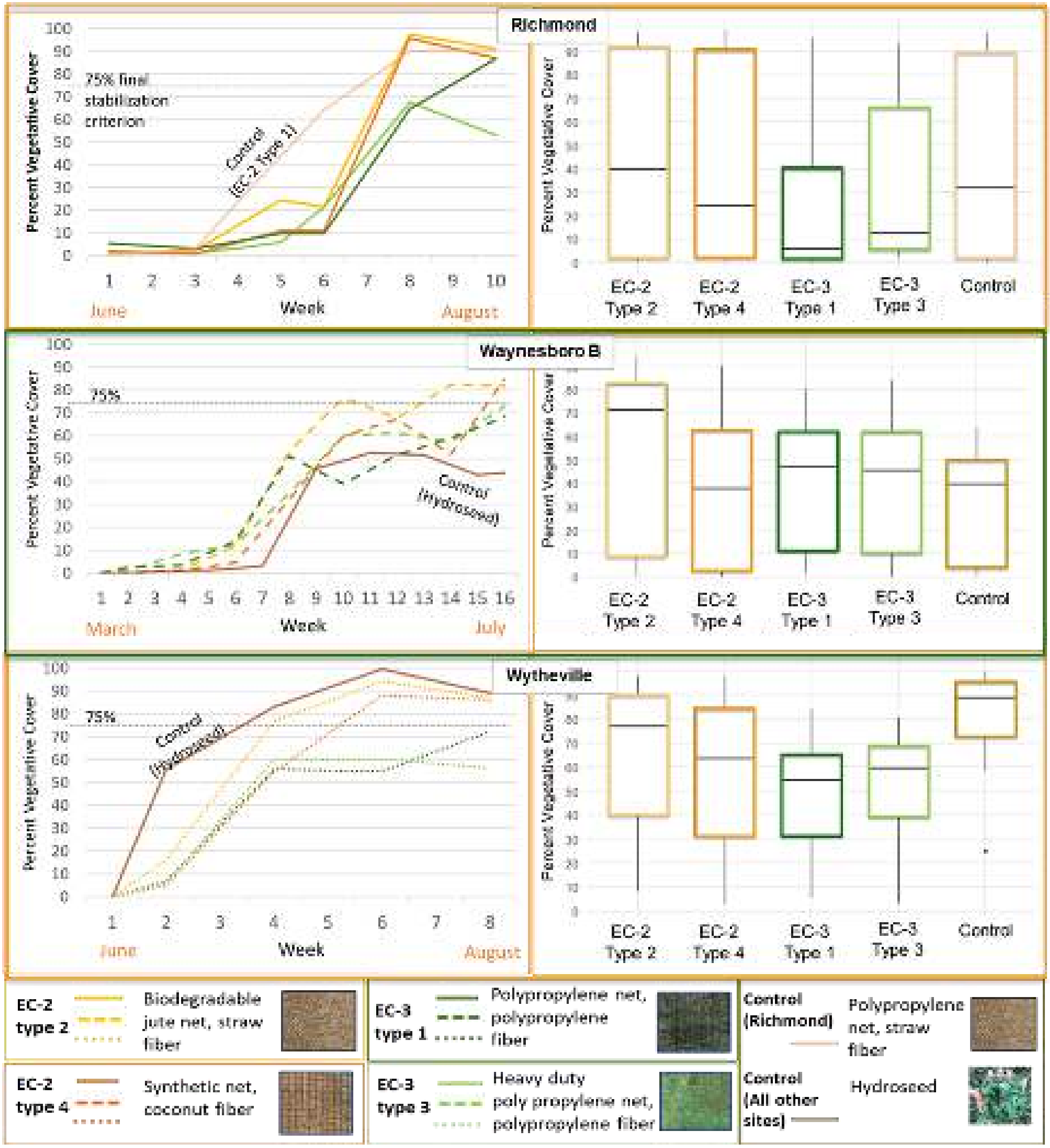


Figure 7. Percent Cover (left) for the Standard Seed Mix and Box Plots (right). The box plots illustrate distributions of the data. The horizontal line in each of the box plots represents the median percent cover, with 75th and 25th percentiles represented by the upper and lower portions of the box, respectively.

The number of weeks for the first RECPs to reach final stabilization, excluding the Waynesboro A site, varied between 4 and 10 weeks. EC-3 Type 2 mats reached final stabilization 2 to 8 weeks earlier than the EC-3 mats that achieved or neared final stabilization. Vegetation was slowest to establish at the Waynesboro B site, which was seeded in March, compared with the other sites that were seeded in June.

Waynesboro A Site

RECPs at the Waynesboro A site remained well below the final stabilization threshold during the September-to-November monitoring period (Figure 8). Record precipitation, 19.9 inches of rain in 2.5 weeks, and freezing temperatures likely triggered dormancy before vegetation could establish. Shortly after vegetation began dying off, the contractor erroneously sprayed hydroseed over the study plot. Although monitoring was therefore discontinued, and data analyses were not conducted, the site was visited in the subsequent June—9 months after seeding. Although the findings from this site visit were anecdotal, the study site as a whole appeared to have reached final stabilization, and flowering vegetation had grown in each of the pollinator subplots. The fact that vegetative cover appeared established across the site as a whole may indicate that RECPs helped protect the seeds and seedlings from dislodging during the extended period of heavy rainfall the previous fall.

Figure 8. Vegetative Cover Results at the Waynesboro A Site in the Fall of 2024 (top) and Study Site Photographs in June 2025 (bottom)

Seed Mixes

The two-way ANOVA showed that seed mix did not significantly influence the percent cover at any site ($p > 0.05$). Full statistical results are available in the supplemental file. Furthermore, for the two-way ANOVA, the interaction between seed mix and RECP type was also not statistically significant; the percent cover remained similar across all combinations of RECPs and seed mix. Figure 9 shows the relationship between seed mix and RECP for the Richmond site. Figure 10 illustrates an example of vegetative cover results by seed mix at the Wytheville site.

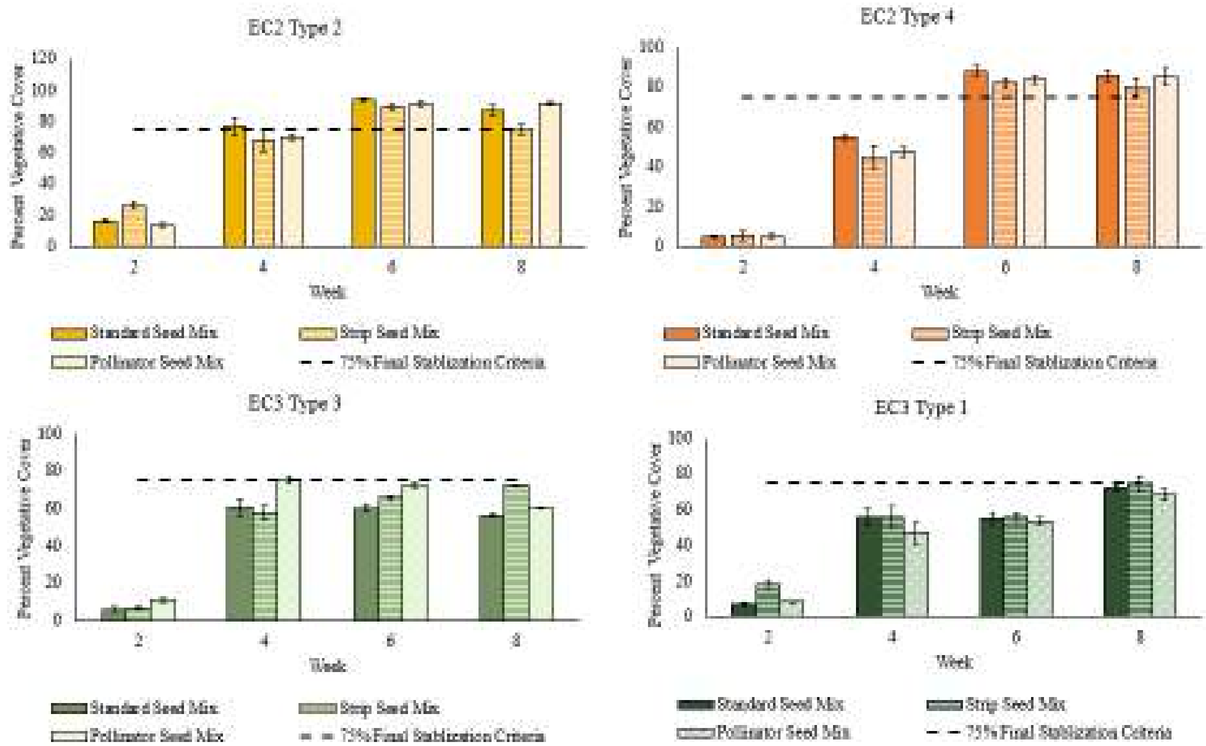


Figure 9. Percent Cover by Seed Mix and Rolled Erosion Control Product Type at the Richmond Site

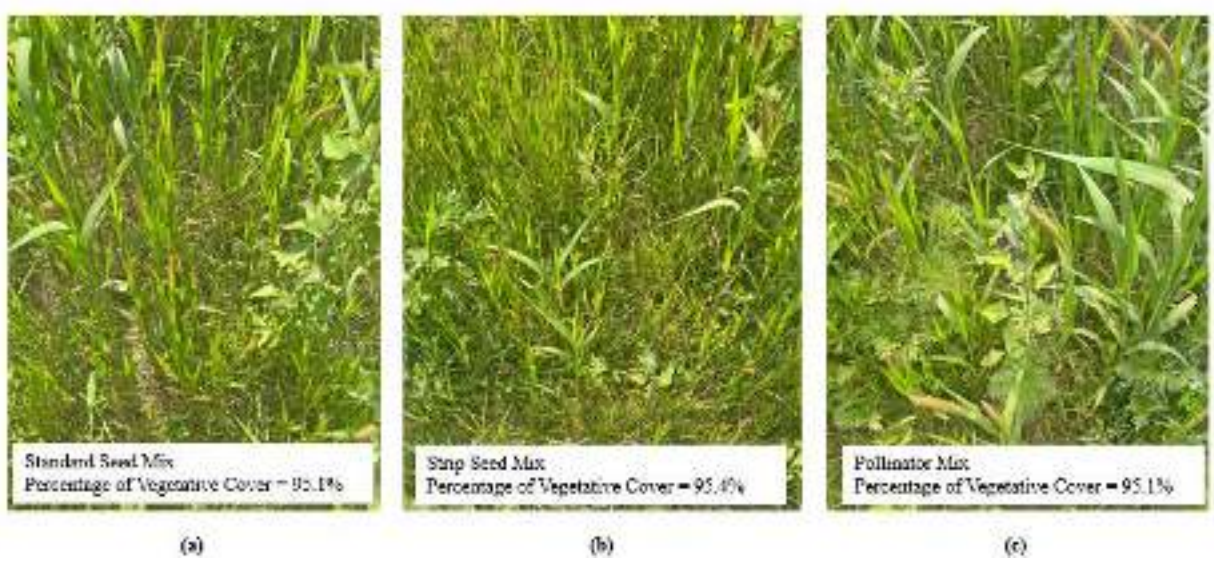


Figure 10. Vegetation Growth in the EC-2 (Type 2) Plot at the Wytheville Site by Seed Mix. Vegetation growth between seed mixes was not statistically significant ($p > 0.05$).

Although many pollinator species take more than one growing season to flower, some blooms were visible in all the pollinator mix subplots near the time of final stabilization. Based on field observation, flower abundance was greatest at the Waynesboro A and Wytheville sites (Figure 11).

Figure 11. Flowering Vegetation in the Pollinator Subplots of (a) Richmond, (b) Waynesboro A, (c) Waynesboro B, and (d) Wytheville Sites. Figure 11d shows a pollinator insect (goldenrod soldier beetle).

Weather and Soil Variables

Precipitation, air temperature, soil temperature, and soil moisture (measured as volumetric water content) were analyzed for their relationships with the percent cover. The Waynesboro A site was excluded from these analyses because vegetation growth was halted during the prolonged period of heavy precipitation followed by freezing temperatures.

Based on ridge regression, Table 8 lists the positive and negative associations of weather and soil variables with vegetative growth. The ridge regression had a high predictive ability at all three sites (coefficient of determination, $R^2 = 0.83$, $R^2 = 0.742$, $R^2 = 0.80$), indicating that precipitation, air temperature, and soil temperature and moisture were reliable predictors of vegetative growth. Full regression equations are included in a supplemental file. Evaluating RECPs as a whole, two variables were consistently associated with growth. These variables include higher daily maximum temperatures, which adversely affected vegetative cover, and precipitation, which had a slight positive effect. In general, milder spring and summer temperatures (higher daily minimum air and soil temperatures and lower daily maximum air temperatures) were associated with higher percent cover. At all sites, vegetation did not emerge until at least one rain event occurred, which explains the initial delay in growth at the Richmond and Wytheville sites (Figure 6).

Given the differences in vegetation growth between EC-2 and EC-3 mats, soil temperature and moisture were compared among the groups using the paired t-test at each site. Across sites, fully synthetic EC-3 plots generally maintained higher maximum soil temperatures than EC-2 plots, with a significantly higher average difference of 6.4°F at the Richmond site ($p = 0.00015$), a higher average difference of 2.4°F at the Waynesboro B site ($p = 0.0064$), and a higher average difference of 3.1°F at the Wytheville site (not significant; $p = 0.134$). Findings suggest that when seeds are planted during warmer periods (e.g., during June at the Richmond and Waynesboro B sites), the already elevated soil temperatures are further increased in EC-3 plots, exaggerating the adverse effects of maximum soil temperature on vegetative cover. It should be noted that these effects may not apply with fall seeding applications when air temperatures decline after seeding.

Table 8. The Effect of Weather and Soil Variables on Vegetative Cover

Weather and Soil Variables		Effect on Vegetative Cover [a]		
		Richmond	**Waynesboro B**	**Wytheville**
Air Temp	Max	--	--	-
	Min	++	++	--
Soil Temp	Max	--	--	+
	Min	+	++	0
Soil Moisture		+	-	-
Precipitation		+	+	+

+ / - = noticeable but slight positive or negative effect ($0.05 \leq |\beta| < 0.20$); ++ / -- = clear effect ($|\beta| \geq 0.20$); 0 = no meaningful effect ($|\beta| < 0.05$). [a] A coefficient value $|\beta|$ was used to determine the effect of variable on vegetative cover. These values were chosen based on natural clusters of data in site models.

Soil moisture (volumetric water content) in EC-3 plots was significantly less than soil moisture in EC-2 plots at Richmond ($p = 0.0014$) and Waynesboro B ($p = 0.0014$) but significantly higher in EC-3 plots at the Wytheville site ($p = 0.020$). The fact that Wytheville's EC-3 plots had a lower percent cover compared with EC-2 plots, yet higher soil moisture values, suggests that soil moisture alone is not a predominant driver of vegetative growth. Figure 12 (Richmond site) illustrates the more common pattern of higher soil temperature and lower soil moisture in EC-3 plots compared with EC-2 plots.

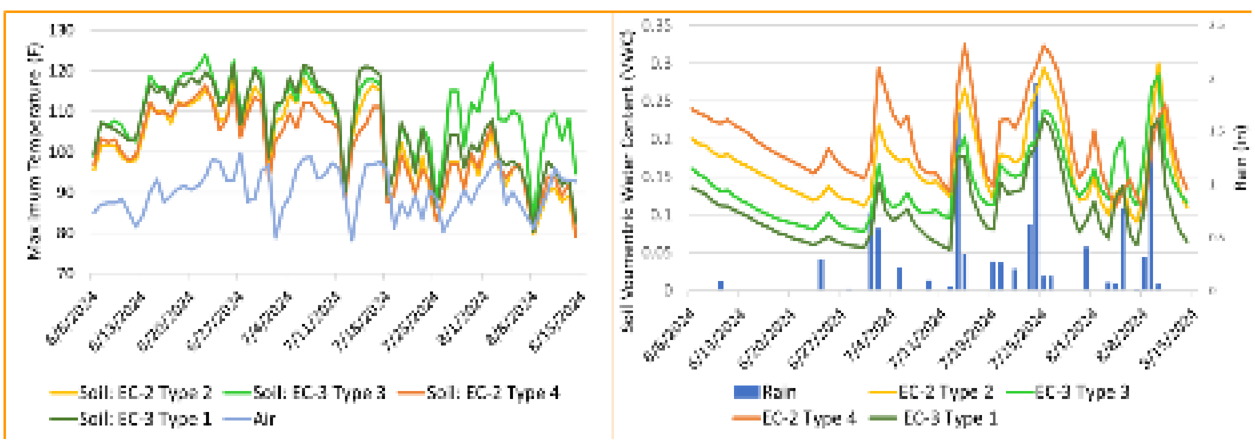


Figure 12. Maximum Daily Soil Temperature (left) and Soil Volumetric Water Content (right) at the Richmond Site

As Figure 12 illustrates, EC-2 Type 4 (coconut fiber) plots typically maintained the lowest maximum soil temperatures and highest soil moisture levels. Although these favorable soil conditions in EC-2 Type 4 plots did not consistently translate into the highest vegetative cover, percent cover was higher in the coconut fiber plots compared with both synthetic EC-3 plots at the Richmond and Wytheville sites (Figure 7). Another notable finding was that, as a vegetative canopy developed in most RECP plots (toward the end of July in Figure 12), two patterns were evident: (1) soil temperatures decreased, tracking more closely with air temperatures and (2) variation in soil moisture among RECPs decreased. These patterns reflect the temperature-dampening and moisture-retaining effects of the vegetation. In the RECP plots with less vegetative cover in the final weeks of the monitoring period, particularly with the EC-3 Type 3, the soil temperatures remained elevated (Figure 12, left).

Field Observations

At all four study sites, both of the evaluated EC-3 mats appeared to have numerous patches with little to no vegetation, which is consistent with the percent cover findings (Figures 6 and 7). These light green (EC-3 Type 3) and dark green (EC-3 Type 1) bare patches are visible in Figure 13.

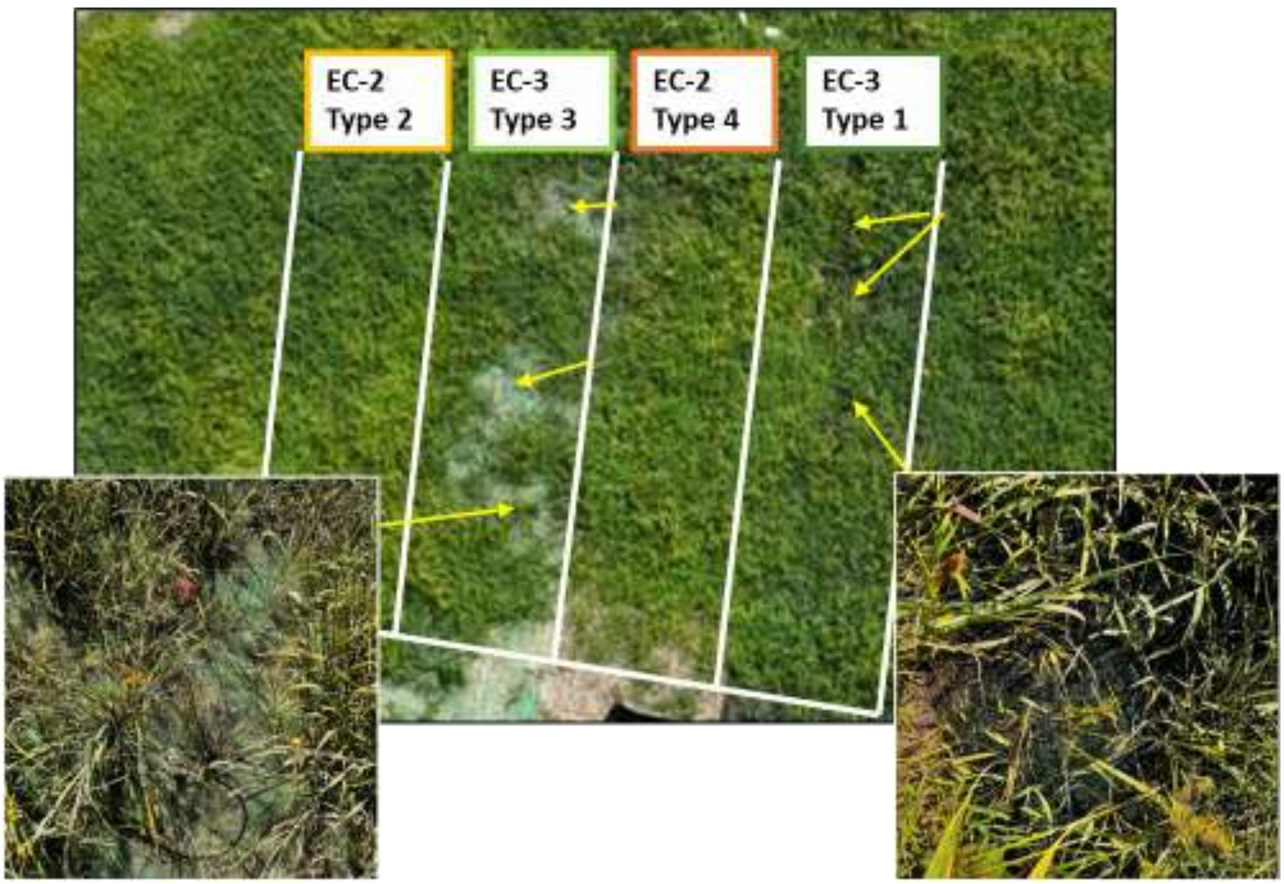


Figure 13. Rolled Erosion Control Product Plots at the Richmond Site, Week 9 (top) and Waynesboro B site, Week 16 (bottom). The plots illustrate the visible bare patches of the light green EC-3 Type 3 mat and the dark green EC-3 Type 1 mat. Bare patches on the dark green EC-3 Type 1 mat are difficult to see in the upper image; large areas of sparse vegetation are indicated by arrows.

Observations regarding RECP material properties and associated installation issues include the following:

- EC-2 Type 2 conformed easily to the soil surface compared with the other evaluated RECPs. This flexibility was especially important at sites with numerous rocks or large clumps of soil. The more rigid EC-3 mats were less accommodating with uneven soil surfaces, resulting in less contact between the mat and the soil.
- Because of the reduced flexibility of EC-3 mats, they required more careful installation to reduce bunching and to attempt to keep the material in contact with the soil. EC-3 mats had to be stretched at the edges to flatten folds, and the number of staples and spacing was especially important. At the Waynesboro sites that were particularly rocky, staples would bend more often from hammering, which may have resulted in fewer staples than were necessary to minimize folds and bunching of EC-3 mats (Figure 14).
- Although the folding of both EC-3 mats' outer netting was evident at all study sites during installation, bunching of the fibers was evident for the EC-3 Type 3 mats at the time the mats were unrolled. This uneven distribution of fibers resulted in some thick areas of fiber and other areas within the netting with very little fiber.
- Reduced void space from the fiber bunching in EC-3 Type 3 mats, along with the high fiber density of EC-3 Type 1 mats, restricted the vegetation from penetrating the mats in some areas (Figure 14).

Figure 14. Pollinator Subplots of the Waynesboro A Site. Folds and bunched fiber are evident in the EC-3 Type 3 (top left), and folds are evident in the EC-3 Type 1 (top right) after installation and tenting of the rolled erosion control products from vegetation that was unable to penetrate the EC-3 Type 3 (bottom left) and EC-3 Type 1 (bottom right).

DISCUSSION

Rolled Erosion Control Product Performance

At all sites where final stabilization was achieved, EC-2 Type 2 mats consistently reached final stabilization more rapidly and maintained higher percent cover values than the other evaluated RECPs. These results held true across the various soil types and site conditions, and despite the uniform application of fertilizer and lime, rather than tailoring application rates to soil test recommendations. Both EC-3 mats underperformed compared with the EC-2 Type 2 mat, with EC-3 Type 1 remaining below the 75% threshold at all sites. Findings suggest that the superior performance of the EC-2 Type 2 mat was linked to material properties that facilitated strong soil contact and moderated soil temperature. The hotter soil conditions generally found in EC-3 plots contributed to the slower and less consistent vegetative cover observed relative to EC-2 mats.

Compared with degradable EC-2 mats, EC-3 mats provide higher tensile strength and durability, which likely explains why DOT specifications often require extended-term or permanent mats as slope gradient increases and soil erosion is a concern (Maryland Department of the Environment, 2011; VDOT, 2020). Although natural fiber RECPs (e.g., coir, straw, jute) have been found to perform well for erosion control, particularly with regard to reducing the initiation of runoff and lowering total soil losses (Jahja et al., 2024), research has also shown that synthetic RECPs can reduce soil loss more effectively during extreme rainfall events and on very steep slopes (Álvarez-Mozos et al., 2014; Smith and Bhatia, 2009). Because of this finding, transportation and contractor staff may believe synthetic mats are more reliable in meeting regulatory requirements and therefore select them over less expensive biodegradable products (Askew et al., 2023).

Although protecting steep slopes from extreme precipitation events is an important consideration in the weeks prior to vegetation establishment, the speed at which vegetation establishes may be a more important benchmark for many VDOT projects. Because vegetation establishment is both the key factor for long-term erosion control (Álvarez-Mozos et al., 2014; Smith and Bhatia, 2009) and the sole stabilization criterion for VDOT project closeout, selecting products that achieve faster vegetation growth outweighs any potential short-term benefits of synthetic mats under extreme conditions.

Although this study did not evaluate erosion control with regard to soil loss, the findings at the Waynesboro A site may provide insight into the erosion protection benefits of the degradable EC-2 mats. An extended and extreme period of rainfall—nearly 20 inches in 2.5 weeks—did not dislodge seeds and seedlings, as evidenced by vegetation establishment at the site the following spring. Although the extent of erosion reduction could not be confirmed, this result indicates that even the most degradable RECP likely contributed to soil stabilization and protected seeds and emerging seedlings from washing out.

In addition to the faster vegetative growth with the EC-2 Type 2 mat, EC-2 mats are more likely to contain biodegradable materials, which have been noted as advantageous because they allow the right amount of time for slopes to establish vegetation before the material degrades

(Kalibová et al., 2016). A review of RECP research found that when biodegradable RECPs made from natural fibers break down, they not only reduce soil loss (Prosdocimi et al., 2016) but also measurably improve key soil quality metrics (Faucette et al., 2006; Syakir et al., 2021). For example, straw has been found to raise soil organic matter content and enhance the availability of nutrients, leading to higher crop yields (Stagnari et al., 2014).

Field observations indicated that the physical properties of the RECP materials directly influenced vegetation growth. The folding and bunching of the EC-3 products appeared to create two primary issues: (1) reduced soil contact, which can limit vegetation establishment by reducing the infiltration of precipitation into the soil (Chen et al., 2011), and (2) restricted vegetation emergence due to difficulty penetrating the dense netting and fibers. The greater strength and tighter weave of the synthetic material may have inhibited plant growth in contrast to the straw-based EC-2 Type 2 mat, which provides looser material that may be easier for vegetation to push through. The tighter weave of synthetic RECPs has also been reported to create other challenges. In this study, two different groups of contract staff assisting with RECP installation noted a preference for EC-2 Type 2 products, partly based on their prior experiences with synthetic RECPs that have not degraded years following installation, causing entanglement for equipment and wildlife. Multiple DOTs noted similar problems in a National Cooperative Highway Research Program evaluation of erosion and sediment control practices, and some DOTs are restricting or adding limits to the use of fully synthetic RECPs (Whitman et al., 2025). Finally, the looser structure that straw mats provide may also provide an advantage for sites that require overseeding if initial establishment fails, as seeds broadcast over these products may be more likely to reach the soil surface.

Options for Selecting Higher Performing Erosion Control Products

The relatively poor performance of EC-3 mats observed in this study suggests that VDOT would benefit from prioritizing the use of EC-2 Type 2 mats on slopes. Potential mechanisms for reducing the use of EC-3 mats include:

- Removing EC-3 products as options on slopes with gradients up to 2:1 in the next update to the *2020 Road and Bridge Specifications* and as a supplemental specification in the meantime (VDOT, 2020).
- Establishing limits on EC-3 use by capping the percentage of EC-3 mats for slope projects.
- Incorporating language in VDOT's upcoming Manual of Landscape Design Guidelines to provide VDOT with greater oversight over contractor product selection for vegetation establishment on slopes.

Effect of Seed Mix on Performance

Although vegetative growth varied by RECP type, the seed mix did not influence growth. All three seed mixes were dominated by fescues, which have a strong stress tolerance and are commonly used for erosion control. Unlike the standard mix and pollinator mix, which each comprised more than 80% fescues, the strip mix included a large proportion of pasture grass and legumes, some of which are known to establish quickly and others that benefit pollinators (i.e., clover and trefoil). The finding of no significant difference among seed mixes supports ongoing updates to VDOT standards documents and the seeding recommendation tool and suggests that supplementing the basic seed mix design with specialty mixes can be based on project goals (e.g., supporting pollinator species).

Additional Implications for Vegetation Establishment

Two additional observations from this study may help inform practices to improve vegetation establishment. The first concerns encouraging the use of soil testing rather than the default applications of fertilizer and lime. Although the unnecessary use of lime at the Wytheville site, which had a neutral pH, did not appear to affect vegetation establishment overall, applying fertilizer or lime without site-specific justification increases costs and potentially hinders establishment. Incorporating soil tests to guide nutrient applications could therefore reduce costs and support more effective vegetation growth.

The second consideration involves watering following seeding. According to VDOT's *2020 Road and Bridge Specifications*, Section 606.03(4), the contract price for RECP installation on slopes "…shall include furnishing, installing, preparing seed beds; and furnishing and applying lime, seed, fertilizer, mulch for seeding, and watering" (VDOT, 2020). However, in areas outside each of the site's study plots, contractors were not observed watering after seeding. In this study, vegetative growth was only detected following the first rainfall events, which occurred weeks later at some sites, and precipitation directly influenced the percent cover across the monitoring periods. These findings suggest that vegetation establishment could be improved if sites were watered within the first few days following seeding and, if feasible, during extended dry periods.

CONCLUSIONS

- *Field results showed that degradable EC-2 mats reliably supported vegetation growth and met permanent stabilization thresholds on 2:1 slopes, with EC-2 Type 2 (jute netting and straw fiber) mats reaching the 75% final stabilization criterion earliest and sustaining the highest percent cover in all study sites.*

- *EC-3 Type 3 (synthetic netting and fiber) mats remained below the final stabilization threshold during the monitoring period at all sites, and EC-3 Type 1 remained below the threshold at two sites.*

- *Seed mix type did not influence the percent cover, regardless of RECP type.* Vegetation growth was not different when using VDOT's standard seed mix compared with subplots where it was enhanced with strip mix or pollinator mix. This outcome indicates that seed mix selection can instead be based on project goals (e.g., supporting pollinator species), seed availability, and cost.

- *Supplementing VDOT's basic seed mix design (i.e., fescues, cover crops, legumes) with specialty seeds (i.e., strip mix and pollinator mix) was found to be equally effective for* *vegetative growth.* These results support ongoing updates to VDOT standards (e.g., *2020 Road and Bridge Specifications*, Manual of Landscape Design Guidelines, and Nature-Based Solutions Standards) and the seeding recommendation tool, which incorporates the basic seed mix design and specialty seed enhancements evaluated in this study.

- *Weather conditions influenced vegetative growth.* Precipitation was necessary to trigger germination, and milder seasonal temperatures supported better growth. Extreme conditions of prolonged heavy rainfall, freezing temperatures, or high daily maximum temperatures reduced vegetative cover.

- *Soil conditions in EC-3 plots were consistently warmer and generally drier than those in EC-2 plots, which may have contributed to the slower vegetation establishment and less consistent vegetative cover in EC-3 plots.* Soil beneath EC-3 mats maintained higher temperatures than soil beneath EC-2 mats at all sites and lower soil moisture at two of three sites.

- *Anecdotal observations suggest that RECP material characteristics affected vegetation establishment*. EC-2 Type 2 was the most flexible and conformed better to uneven or rocky slopes, whereas EC-3 mats were more rigid, were prone to folding and bunching, inhibited plant emergence in some areas, and required more careful installation procedures.

- *Two practical guidelines are expected to improve vegetation establishment: watering after seeding (and during extended dry periods, when feasible) and soil testing to guide the application of fertilizer and lime.*

RECOMMENDATIONS

1. *VDOT's Location and Design Division should prioritize the use of EC-2 Type 2 RECPs in place of EC-3 products on slopes with a gradient up to 2:1 (i.e., one unit of vertical rise for every two units of horizontal run).*

2. *VDOT's Construction Division and Maintenance Division should continue implementing VDOT's updated framework for seed mix selection, which includes options for pollinator and strip specialty mixes, with selections based on specific project goals.*

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, within 1 year of this report's publication, the State Location and Design Engineer will coordinate with the Construction Division and other relevant divisions to implement language in relevant documents that will increase the selection of EC-2 Type 2 mats over EC-3 mats on slopes up to 2:1.

Initial coordination with the Location and Design Division confirmed that relevant language in the forthcoming Manual of Landscape Design Guidelines will be consistent with this recommendation.

With regard to Recommendation 2, within 6 months of this report's publication, the State Construction Engineer will coordinate with the Maintenance Division, District Construction Engineers and other relevant divisions to implement a seeding contractor checklist for use by construction inspectors and contract staff. The VDOT State Roadside Program Supervisor is creating a draft checklist that incorporates the standard seed mix and specialty seed mix designs evaluated in this study. A comparable checklist used in the Staunton District has been highly effective at strengthening coordination between VDOT and contract staff and serves as a model for this effort.

In addition, some sections of the forthcoming Manual of Landscape Design Guidelines related to seeding and vegetation establishment will include language applicable to the Construction and Maintenance divisions for seeding and vegetation establishment. The guidelines will inform contractor coordination with DRMs to better ensure the Roadside Development Sheet specifies seed mixes, seeding schedules, application rates, topsoil depth, and nutrient requirements. The guidelines will also align with the practical recommendations in this report regarding soil testing to guide nutrient application and watering during the vegetation establishment phase.

Benefits

Recommendation 1

As described previously, a project cannot be released from stormwater permit coverage until evenly distributed ground cover provides at least 75% vegetative cover. The primary benefit of reaching this milestone in project delivery is the cost savings and time efficiency gained by avoiding the need to reseed the site and the associated delays in permit release. Although these costs are difficult to quantify on a statewide scale, the greatest benefit comes from adopting practices that accelerate vegetation establishment.

In the absence of statewide cost data related to reseeding or permit delays, VDOT expenditures on RECP products were quantified. VDOT's bid history data were reviewed to assess RECP costs, installation quantities, and the potential cost savings from greater use of EC-2 Type 2 in place of other RECPs. Table 9 lists the average weighted bid price for the most recent 5 years of available data (2019 to 2024). Average weighted bid prices were obtained from VDOT's Construction Bid Tab tool on Power BI, which provides a weighted average bid price for each RECP type. Average weighted bid prices for EC-3 mats were 62.2% higher than those for EC-2 mats.

Table 9. Average Bid Price Data for RECPs for 2019–2014

RECPs		Average Weighted Bid Price (5 years)	
		Per Square Yard	Average
EC-2	Type 1	$2.70	$3.75
	Type 2	$3.60	
	Type 3	$4.70	
	Type 4	$4.00	
EC-3	Type 1	$6.10	$5.50
	Type 2	$4.70	
	Type 3	$5.70	

RECPs = rolled erosion control products.

Using the installation quantities (square yards) per project, which were also obtained from VDOT's Cost Estimation Bid Tab tool, annual costs were calculated for each RECP type by multiplying the installation quantity by its average weighted bid price. Figure 15 illustrates the annual average installation quantities and costs for the most recent 7 years of data (June 2017 to June 2024). During this period, EC-3 Type 1, the only RECP in this study that failed to achieve final stabilization at any site, cost VDOT more than any other RECP. Among the RECPs approved for slopes steeper than 3:1 (all except EC-2 Type 1), the average annual quantity installed was 17.2% lower for EC-3 mats than for EC-2 mats, yet the annual costs of EC-3 mats were 30.4% higher. The higher price per square yard of EC-3 mats drives this cost difference.

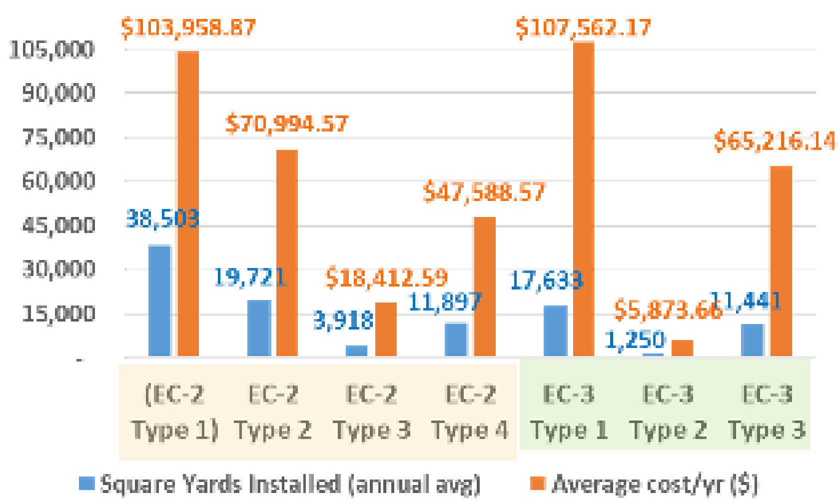


Figure 15. Rolled Erosion Control Product Installation Quantities and Costs (Annual Average) from VDOT Bid History Data

Given the performance of EC-2 Type 2 in this study and its lower cost compared with EC-3 mats, an evaluation was conducted to estimate potential cost savings if EC-2 Type 2 mats replaced all or a portion of the RECPs used on VDOT projects. Using 7 years of VDOT bid history data, Table 10 summarizes the cost savings if EC-2 Type 2 mats replaced 100%, 75%, or 50% of the other RECPs approved for use on slopes steeper up to 2:1.

Table 10. Cost Savings if EC-2 Type 2 Mats Replaced 100%, 75%, and 50% of all other RECPs Approved for Use on Slopes Steeper than 3:1

Cost Savings	Replacement of RECPs with EC-2 Type 2		
	100%	**75%**	**50%**
One year period	$78,553	$58,915	$39,276
Ten year period	$785,52	$589,145	$392,764

RECPs = rolled erosion control products.

As noted previously, the cost savings in Table 10 are conservative estimates that do not account for the costs of project delays or revegetating or overseeding a project if initial establishment fails. Results from this study indicate that for projects that use an RECP on a 2:1 slope, re-establishment efforts are least likely to be required when an EC-2 Type 2 product is selected.

Recommendation 2

Regarding Recommendation 2, VDOT's continued use of the specialty seed mixes (i.e., strip and pollinator mixes) provides VDOT with the flexibility to use mixes that have been shown to meet establishment thresholds, allowing seed mix selection to be based on project goals, seed availability, and cost. This recommendation also supports a landscape framework reflected in the forthcoming Manual of Landscape Design Guidelines to expand the use of specialty seed mixes for herbaceous meadow land cover.

The checklist under development, along with forthcoming language in the Manual of Landscape Design Guidelines on contractor coordination with DRMs, will enhance collaboration between coordination of VDOT and contract staff and strengthen the role of construction inspectors and DRMs in seed mix approval and oversight.

ACKNOWLEDGMENTS

This study benefited from the insight and feedback provided by the individuals who served on the technical review panel for this study: Beau Hoyt (project champion), Nick Gerardi, John Rogers, Nicholas Potter, Jacob Bauckman, and Shabbir Hossain. Appreciation is also extended to Mike Fitch and John Miller of VTRC for their support and feedback and to Emmett Heltzel, Alex Foraste, and Martin Krebs for their review and input. The authors would like to thank Bill Lewis for providing seed mix quantities and his invaluable project support. The study also benefited from the support of Larry Newman, who served as an indispensable source of information and assisted with field installation.

The field evaluations in this study would not have been possible without the help of VDOT and contract staff: Kendall Allen, Skip Vest at Dickerson Construction, Mike Freid, Josh Andelin, Stephanie Stein, Josh Hall, Stephen Wright, Nate Adkins at Branch Civil, Bradley Weaver at ATCS, Jared Salts, Todd Bolling, and James Parsons.

The authors would also like to thank the many VTRC engineering technicians and interns who supported this project. Thank you to Michael Epperson and Emma Weinstein for collecting field data and assisting with field installations. Thank you to Jonathan Luu for assistance with the statistical analyses of field data. Appreciation is also extended to Paxton Gunn, Isabel Xiao, Adrian Blackstone, Noah Nauman, Mason Pearce, and Abdullatif Yahia for assisting with field installations.

REFERENCES

Álvarez,-Mozos, J., Abad, E., Goñi, M., Giménez, R., Camp, M.A., Díez, J., Casalí, J., Arive, M., and Diego, I. Evaluation of Erosion Control Geotextiles on Steep Slopes. Part 2: Influence on the Establishment and Growth of Vegetation. *Catena*, Vol. 121, 2014, pp. 195–203.

Askew, S.D., Goatley, J.M., and Goncalves, C. *Promoting Native Roadside Plant Communities and Ensuring Successful Vegetation Establishment Practices*. Virginia Transportation Research Council, Charlottesville, VA, 2023.

ASTM International. *ASTM D6459-19: Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion. In Annual Book of ASTM Standards*. West Conshohocken, PA, 2019.

ASTM International. *ASTM D7322/D7322M-23: Standard Test Method for Determination of Erosion Control Product (ECP) Ability to Encourage Seed Germination and Plant Growth Under Bench Scale Conditions. In Annual Book of ASTM Standards*. West Conshohocken, PA, 2023.

Benik, S., Wilwon, B., Biesboer, D., Hansen, B., and Stenlund, D. Performance of Erosion Control Products on a Highway Embankment. *Transactions of the ASAE*, Vol. 46, No. 4, 2003, pp. 1113–1119.

Bhattacharyya, R., Smets, T., Fullen, M.A., Poesen, J., and Booth, C.A. Effectiveness of Geotextiles in Reducing Runoff and Soil Loss: A Synthesis. *Catena,* Vol. 81, 2010, pp.184–195.

Chen, S.C., Chang, K.T., Wang, S.H., and Lin, J.Y. The Efficiency of Artificial Materials used for Erosion Control on Steep Slopes. *Environmental Earth Sciences*, Vol. 62, 2011, pp. 197–206.

Faucette, L.B., Risse, L.M., Jordan, C.F., Cabrera, M.L., Coleman, D.C., and West, L.T. Vegetation and Soil Quality Effects from Hydroseed and Compost Blankets Used for Erosion Control in Construction Activities. *Journal of Soil and Water Conservation*, Vol. 61, No. 6, 2006, pp. 355–362.

Federal Highway Administration. *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects: FP-03, U.S. Customary Units*. FHWA-FLH-03-002. U.S. Department of Transportation, Washington, DC, 2003.

https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/specs/archives/14306/fp-03usc.pdf.

Fullen, M.A., and Booth, C.A. Grass Ley Set-Aside and Soil Organic Matter Dynamics on Sandy Soils in Shropshire, UK. *Earth Surface Processes and Landforms*, Vol. 31, No. 5, 2006, pp. 570–578.

Galbraith, J.M., and Baker, J.C. Soils of Virginia. Part VI: Soils of Virginia. *Agronomy Handbook*. Virginia Cooperative Extension, Blacksburg, VA, 2023, pp. 103–114. https://www.pubs.ext.vt.edu/424/424-100/424-100.html.

Jahja, M., Mudatstsir, A., Supu, I., Arifin, Y. I., Rauf, J., Sakakibara, M., Yamaguchi, T., Metaragakusuma, A. P., and Butolo, I. How effective are palm-fiber-based erosion control blankets (ECB) against natural rainfall? *Sustainability*, Vol. 16, No. 4, 2024.

Kalibová, J., Jačka, L., and Petrů, J. The Effectiveness of Jute and Coir Blankets for Erosion Control in Different Field and Laboratory Conditions. *Solid Earth*, 2016, Vol. 7, No. 2, pp. 469–479.

Karcher, D., Purcell, C., and Hignight, K. *Devices, Systems and Methods for Digital Image Analysis*. U.S. Patent Application No. 17/744,900, n.d.

Karcher, D., and Richardson, M. Digital Image Analysis in Turfgrass Research. *Turfgrass: Biology, Use, and Management*, Vol. 56, 2013, pp. 1133–1149.

Manning, C., Faulkner, B., and Donald, W. Comparison of Erosion Control Products Using an ASTM D6459 Rainfall Simulator: Insights and Suggestions. *Journal of Irrigation and Drainage Engineering*, Vol. 149, No. 8, 2023.

Maryland Department of the Environment. *Maryland Standards and Specifications for Soil Erosion and Sediment Control*. Baltimore, MD, 2011. https://mde.maryland.gov/programs/water/StormwaterManagementProgram/Documents/2011%20MD%20Standard%20and%20Specifications%20for%20Soil%20Erosion%20and%20Sediment%20Control.pdf.

McKinney, J.L. *Nutrient Management Plan Vegetation Establishment on Construction Projects*. Virginia Department of Transportation, Lynchburg VA, 2023. https://www.vdot.virginia.gov/media/vdotvirginiagov/doing-business/technical-guidance-and-support/technical-guidance-documents/maintenance/Signed_NMP_-Construction_-2023_JLM-final_acc.pdf.

Ogbobe, O., Essien, K.S. and Adebayo, A. A Study of Biodegradable Geotextiles Used for Erosion Control. *Geosynthetics International*, Vol. 5, No. 5, 1998, pp. 545–553.

Ola, A., Dodd, I.C., and Quinton, J.N. Can We Manipulate Root System Architecture to Control Soil Erosion? *SOIL*, Vol. 1, No. 2, 2015, pp. 603–612.

Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A., and Cerdà, A. The Immediate Effectiveness of Barley Straw Mulch in Reducing Soil Erodibility and Surface Runoff Generation in Mediterranean Vineyards. *Science of the Total Environment*, Vol. 547, 2016, pp. 323–330.

Rickson, R.J. Controlling Sediment at Source: An Evaluation of Erosion Control Geotextiles. *Earth Surface Processes and Landforms*, Vol. 31, No. 5, 2006, pp. 550–560.

Smets, T., Poesen, J., Fullen, M.A., and Booth, C.A. Effectiveness of Palm and Simulated Geotextiles in Reducing Run-off and Inter-Rill Erosion on Medium and Steep Slopes. *Soil Use and Management*, Vol. 23, No. 3, 2007, pp. 306–316.

Smith, J.L., and Bhatia, S.K. Evaluation of Vegetated RECPs Using ECTC's Bench-Scale Test. In *Geosynthetics & GRI-22 Conference*, Salt Lake City, UT, 2009, pp. 641–651.

Stagnari, F., Maggio, A., Galieni, A., and Pisante, M. Cover Crops and Mulching as Sustainable Practices in Agro-Ecosystems. *Italian Journal of Agronomy*, Vol. 9, No. 3, 2014, pp. 137–144.

Syakir, M.I.S., Al Manasir, Y., Nor Ashikin, N.S.S., Md Yusuff, M.S., Zuknik, M., and Abdul Khalil, H.P.S. Application of Cellulosic Fiber in Soil Erosion Mitigation: Prospect and Challenges. *BioResources*, Vol.16, No. 2, 2021, pp. 4474–4522.

Virginia Department of Conservation and Recreation. Virginia's Nutrient Management Standards and Criteria, 2014. https://www.dcr.virginia.gov/soil-and-water/nutmgt. Accessed January 9, 2024.

Virginia Department of Environmental Quality. *Virginia Stormwater Management Handbook, Version 1.1*. Richmond, VA, 2024.

Virginia Department of Transportation. *Maintenance Division Instructional and Informational Memoranda: Roadside Development, 2016.8.0.* Richmond, VA, 2017, pp. 1–13. https://www.vdot.virginia.gov/doing-business/technical-guidance-and-support/technical-guidance-documents/iim-main-201680-roadside-development/.

Virginia Department of Transportation. *2020 Road and Bridge Specifications*. Richmond, VA, 2020. virginiadot.org/business/resources/const/VDOT_2020_RB_Specs_acc071522.pdf.

Virginia Department of Transportation. *Road Design Manual.* Richmond, VA, 2022. https://www.virginiadot.org/business/locdes/rdmanual-index.asp.

Virginia Department of Transportation. Materials—Approved Products, 2023. https://www.virginiadot.org/business/resources/Materials/ApprovedLists/Materials_Approved_Lists.pdf. Accessed September 28, 2025.

Virginia Department of Transportation. *Drainage Manual*. Richmond, VA, 2025. https://www.vdot.virginia.gov/doing-business/technical-guidance-and-support/technical-guidance-documents/drainage-manual/#d.en.46721.

Whitman, J.B., Schussler, J.C., and Perez, M.A. *Use of Sustainable Materials for Erosion and Sediment Control Practices*. National Academies Press, Washington, DC, 2025. https://doi.org/10.17226/29034.

APPENDIX

Table A1. Strip Seed Mix Contents

Common Name	Percent by Weight
Orchard Grass	28.45%
Annual Rye Grass	24.59%
Timothy	15.79%
Red Clover	11.91%
Perennial Ryegrass	9.8%
Birdsfoot Trefoil	2.91%
Landino Clover	1.93%
Highland Bentgrass	1.9%
Other Crop	0.65%
Weed Seed	0.25%
Inert Matter	1.82%

Table A2. Pollinator Mix Contents

Botanical Name	Common Name	Percentage
Centaurea cyanus - Mixed	Bachelor's Button - Mixed	10.40%
Centaurea cyanus	Bachelor's Button - Blue	10.30%
Delphinium ajacis	Rocket Larkspur	10.00%
Gaillardia aristata	Perennial Gaillardia (Blanketflower)	7.70%
Echinacea purpurea	Purple Coneflower	7.10%
Cosmos bipinnatus	Cosmos	6.50%
Cosmos sulphureus	Sulphur Cosmos	6.50%
Rudbeckia hirta	Blackeyed Susan	5.40%
Gaillardia pulchella	Annual Gaillardia (Indian Blanket)	4.40%
Coreopsis grandiflora, Piedmont GA Ecotype	Largeflower Tickseed, Piedmont GA Ecotype	4.30%
Coreopsis lanceolata	Lanceleaf Coreopsis	4.30%
Chamaecrista fasciculata, FL Ecotype	Partridge Pea, FL Ecotype	4.00%
Phlox drummondii	Annual Phlox	2.50%
Lavatera trimestris	Tree Mallow	2.00%
Monarda punctata, FL Ecotype	Spotted Beebalm, FL Ecotype	1.80%
Asclepias tuberosa, PA Ecotype	Butterfly Milkweed, PA Ecotype	1.40%
Coreopsis basalis, FL Ecotype	Goldenmane Tickseed, FL Ecotype	1.40%
Baptisia pendula, FL Ecotype	Largeleaf Wild Indigo, FL Ecotype	1.20%
Lespedeza virginica, VA Ecotype	Slender Lespedeza, VA Ecotype	1.00%
Oenothera speciosa	Showy Evening Primrose	1.00%
Pycnanthemum incanum	Hoary Mountainmint	1.00%
Helianthus angustifolius, Coastal Plain NC Ecotype	Narrowleaf Sunflower, Coastal Plain NC Ecotype	0.80%
Amorpha herbacea, NC Ecotype	Clusterspike False Indigo, NC Ecotype	0.60%
Rudbeckia amplexicaulis	Clasping Coneflower	0.60%
Silphium asteriscus var. laevicaule, GA Ecotype	Starry Rosinweed, GA Ecotype	0.60%
Solidago speciosa, Coastal Plain GA Ecotype	Showy Goldenrod, Coastal Plain GA Ecotype	0.60%
Eupatorium coelestinum, FL Ecotype	Mistflower, FL Ecotype	0.50%
Baptisia albescens, NC Ecotype	Spiked Wild Indigo, NC Ecotype	0.40%
Papaver rhoeas, Red	Corn Poppy, Red	0.40%
Pycnanthemum tenuifolium	Narrowleaf Mountainmint	0.40%
Coreopsis tinctoria	Plains Coreopsis	0.30%
Lobularia maritima	Sweet Alyssum	0.30%
Penstemon australis, 'Suther'-NC Ecotype	Eustis Lake Beardtongue, 'Suther'-NC Ecotype	0.30%