Evaluation of Effectiveness and Cost-Benefits of Woolen Roadside Reclamation Products: Field Tests

Task 4 Report

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Glossary

Batt	a piece of felted or carded wool material in rolls or sheets
Carding	a mechanical process to disentangle unorganized clumps of wool fiber and align them to be parallel with one another
Felt	a textile that is produced by matting, condensing and pressing fibers, such as wool, together
Needle felt	"barbed" needles in machines enter wool and grab top layers and intertwine them with interior layers of fibers in a continuous repeated process to make wool fabric
Noil	short fiber removed by the combing of wool
Roving	a slightly twisted roll or strand of unspun wool fiber
Scour	the removal of wool wax (lanolin), suint (perspiration), dirt, excrement, dust and other matter from the fleece in water.
Wet felt	warm soapy water is applied to layers of wool and it is repeatedly agitated and compressed to make a single piece of fabric
Worsted	wool or yarns that have a long staple length (4 inch fibers and longer only), are carded *and* combed, are stronger, finer, smoother and harder than woolen yarns/wool

1 INTRODUCTION

This document is the Task 4 Report for evaluating the effectiveness of woolen roadside reclamation products and summarizes the project activities occurring in Task 4. The overall objective of the project is to evaluate wool products that can be used for roadside reclamation by the Montana Department of Transportation (MDT). The project seeks to develop and test potential wool products that can be easily produced as complementary or replacement products to existing traditional best management practices (BMPs) products. Field tests of the woolen products evaluated their effectiveness compared to standard practices.

Previous project tasks were to identify and develop wool products with potential for roadside applications, and to evaluate key geotextile material characteristics of woolen products. Results of these tasks are presented in the Task 2 and Task 3 Reports for the project (Ament et al. 2016a and 2016b).

The primary objective of Task 4 was to evaluate woolen product performance for plant establishment in comparison to existing standard materials via field experiments. Three woolen reclamation products were selected as promising products for testing were:

- Wool silt fence
- Wool erosion control blankets (ECBs) of varying densities, thicknesses and strength
- Wool as an additive to conventional wood-based compost

The objectives for the three categories of wool reclamation products were to:

- Determine if wool silt fence products developed by the project filter sediment, have the strength and durability to withstand typical Montana weather events and roadside water runoff, and have sufficient longevity (1-2 years).
- Compare the effectiveness of different weights and types of wool erosion control blankets (ECBs) developed by the project to traditional straw / coconut ECB, and determine whether each of the wool ECBs resulted in greater vegetative establishment and reduced soil erosion than straw / coconut ECB.
- Determine if 1.9 centimeter (cm) (0.75 inch (in)) cut wool incorporated into wood-based compost outperforms the compost alone.

2 BACKGROUND

Highway right-of-way management following construction on MDT lands requires creating conditions conducive to the establishment and survival of reclamation seeding while controlling soil erosion and surface runoff. Woolen reclamation BMP products have many attributes that may make them superior to existing standard materials. This project seeks to develop and test the effectiveness of wool-based products for erosion control, soil retention and vegetation establishment. Wool products will be compared to existing BMPs that often use imported coconut fiber (coir) in erosion control fabrics or synthetic non-biodegradable geotextile materials.

Erosion control fabrics generally meet the requirements established by the Erosion Control Technology Council and the U.S. Department of Transportation, Federal Highway Administration's standard specifications for construction of roads and bridges on federal highway projects [FP-03 2003 Section 713.17, Type 3.B]. There are several types of erosion control blankets (ECB): temporary, extended, and semi-permanent. One of the most commonly used erosion control blankets produced is comprised of 2 layers of sisal netting filled with straw and coconut fibers (coir) and stitched together. According to several manufacturer's product specs, erosion control blankets have a functional longevity up to eighteen months. These ECB products are intended to reduce soil erosion, water run-off and improve the environment for revegetation. Some ECBs also may provide soil moisture retention to aid in seedling establishment and plant growth.

Roadside reclamation products containing wool may perform similarly or better than traditional straw/coconut ECBs. Scoured weed-seed free wool can store up to 400% of its weight in water (Upton 2003). Wool becomes saturated at 33% of its weight of moisture-free fibers (D'Arcy 1990). That is, when scoured wool absorbs water greater than 33% of its weight, the moisture is readily available for plant growth. This characteristic could make woolen erosion control blanket more advantageous in drier climates and especially in areas with sandy soil. In addition, sheep wool contains up to 17% nitrogen and can act as a slow release fertilizer for plant growth (Herfort 2010). Research from Europe testing the use of woolen fabrics for establishing vegetation on green roofs resulted in over three times more plant canopy cover when wool was used in mats compared to traditional coconut fibers mats (Herfort 2010). Waste wool pellets are also marketed as fertilizer in both the U.S. and Germany (Bohme et al. 2010). In addition to providing fertility, the wool pellets hold 20 times their weight in water (Wild Valley Farms 2016).

In Task 3, a variety of laboratory tests were conducted of various wool and conventional (used as controls) products to determine whether they meet specifications for MDT and Federal Highway Administration (FHWA) deployment. The results were reported in the Task 3 final report (Ament et al. 2016b).

In this Task 4 Report, woolen products developed for the project were evaluated in several field experiments along highways in Montana as well as on a test slope built and maintained by the Western Transportation Institute (WTI) at the Transcend Research Facility.

3 MATERIALS AND METHODS

The research consisted of a series of field tests for newly developed woolen reclamation products produced in cooperation with Montana wool producers and a Minnesota ECB manufacturer. Products were tested at active highway revegetation projects selected by the MDT Reclamation Specialist along U.S. Highway 287 near Three Forks, MT, U.S. Highway 12 near Martinsdale, Montana, and at WTI's Transcend facility in Lewistown, Montana where a constructed test slope (3H:1V) is used for experiments (Figure 1). Three categories of wool reclamation products were developed by the project: 1) silt fence, 2) ECBs and 3) cut wool used as an additive to wood-based compost. They were evaluated at various field sites in Montana during 2015 and 2016. The project sought to evaluate the effectiveness of the wool products and compare them to traditional commercial products currently used by MDT and other state transportation agencies.

There were no known wool silt fence products available anywhere in the world for the project to test. Thus, the first step for silt fence was developmental. Project team members worked with three different wool mills in Montana to better understand how to manufacture wool silt fence. Thus, the development of wool silt fence took a heuristic approach for development and field testing. Ultimately, three different versions of wool silt fence were developed and tested in the field over the two years of the project (see Task 2 and 3 reports). The first version was developed by a Montanan wool mill using wool batts that were stitched together to make a roll of material. The second version was developed by the same wool mill and a canvas shop. The canvas shop had industrial sewing machines with stitching capabilities to sew the wool batts together and add horizontal and/or vertical stitching to strengthen the material. The last version was made with an ECB manufacturer in Minnesota using cut wool pieces placed between two layers of burlap and stitched together. Due to the putative nature of the wool silt fence products developed for the project, data collected to evaluate their functionality was ocular and photographic (observational).

To evaluate the effectiveness of the wool ECBs, the site preparation, seed mix and seed rate were held constant for each of the ECB field locations. Controlling these site variables allowed for a single dependent variable to be measured to assess the efficacy of each wool treatment. Vegetative canopy cover was the sole dependent variable measured during monitoring. The vegetative canopy cover was recorded for each species in each experimental plot so that seeded, non-seeded and weedy species relative abundance could be measured and evaluated statistically. Treatments were replicated eleven times at the Highway 287 research site and ten times at the Transcend site to facilitate statistical inference.

The wool-compost blended product was evaluated similarly to the ECBs. It was compared to a wood-based compost control treatment developed from typical compost prescriptions used regularly by MDT on its post-construction roadside reclamation projects. Site preparation, seed mix and seed rate were identical for both the traditional compost and the compost with wool pieces added. The plant canopy cover was recorded for each species for each experimental plot.

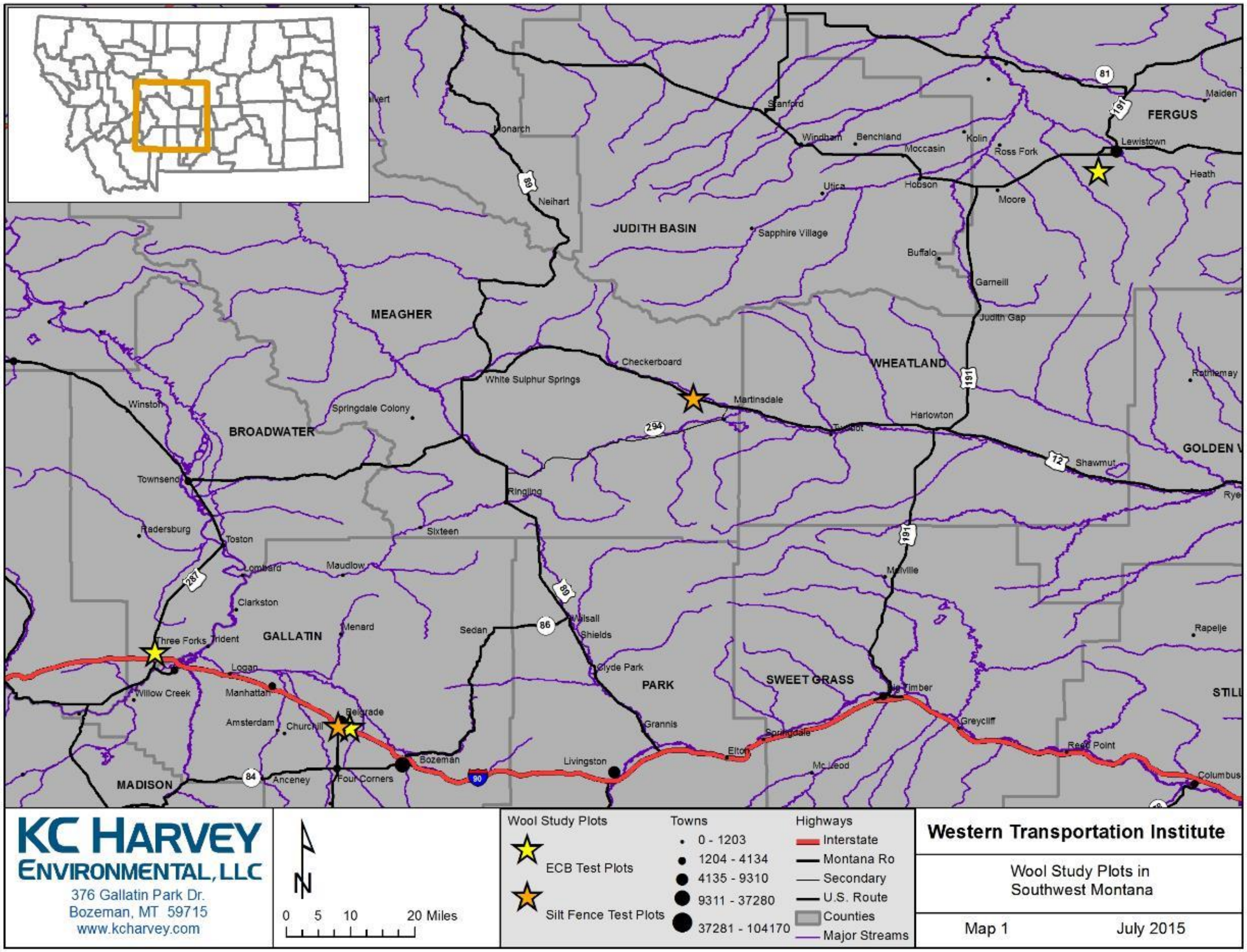


Figure 1. Field test site locations in Montana.

3.1 Silt Fence

Three different generations of wool silt fence were developed and successively installed on the Checkerboard Martinsdale-East highway project (STPP-HSIP 14-2(29)72). The reconstruction project was located on Highway 12 between MP 71 and MP 77. The road surface was widened and straightened to current highway design standards. During reconstruction, topsoil was salvaged, stockpiled and then reapplied at a 2 – 8 cm (1 – 3 in) depth. Roadsides were disked and harrowed, and then all slopes angles 3:1 or less were drill seeded. At the time of initial wool silt fence installation in 2014, the area had been drill seeded; however little to no germination had occurred.

There were four field tests of the first generation of silt fence, which consisted of 100% biodegradable 244 g/m^2 (7 oz/yd^2) wet felted wool batts. The silt fence was manufactured by Sugar Loaf Wool Carding Mill. Each rectangular wool batt was approximately 106.7 cm (42 in) by 91.4 cm (36 in), and was subsequently sewed together by Custom Canvas Design of Bozeman, MT into a continuous roll of wool silt fence 106.7 cm (42 in) wide. The silt fence was installed at the field site on August 28, 2014 (Table 1). The four locations were selected because erosion was visually observed indicating it would provide adequate conditions to test the product's ability to capture sediment, withstand surface runoff volumes typical of MDT roadsides, and endure through the winter and spring conditions. All wool silt fence was installed consistent to standard geotextile silt fence fabric and similar to MDT specifications (see drawing 208-30, Supplemental to the MDT Standard Specifications for Road and Bridge Construction, 2016). A six inch, v-shaped ditch was dug to bury and backfill the bottom six inches of the wool fabric. The above-ground portion of wool silt fence was stapled to 1.2 m (4 ft) tall wood stakes placed at approximately 1 m (3 ft) spacing for support (Figure 2a). The first generation silt fence was monitored in October 2014 and January 2015.

Table 1. Wool silt fence field locations installed August 28, 2014.

Location	Nearest Town	Latitude	Longitude
1	Martinsdale, MT	46°30'31.5144 N	110°23'09.7926 W
2	Martinsdale, MT	46°30'30.9646 N	110°23'10.7120 W
3	Martinsdale, MT	46°30'27.3790 N	110°23'01.6508 W
4	Martinsdale, MT	46°30'22.6742 N	110°22'46.6626 W

The second generation silt fence included stitching to increase strength and longevity of the product. Custom Canvas Design of Bozeman, MT stiched at 10 cm (4 in) intervals into two layers of 140 g/m^2 (4 oz/yd^2) felted wool silt fence (Figure 2b). A plastic mesh net was stitched between the two layers of felted wool to increase strength of the resultant fence. Two second generation silt fences and one plastic geo-textile silt fence (control) were installed in July 2015 at locations 2, 3, and 1, respectively (Table 1). The second generation silt fence was monitored in October 2015 and June 2016.

In February 2016, Rob Ament visited Ramy Turf Products / Ero-Guard in Mankato, Minnesota to observe their ECB manufacturing facility and discuss techniques to improve upon the current wool products. A third generation 100% biodegradable silt fence was designed that consisted of two burlap sheets stitched together with a shredded wool center sandwich. The third generation wool / burlap silt fence was much easier and less costly to produce at larger scales than the previous generation felted wool silt fence. This final version of silt fence for this project could also potentially be used in automated silt fence installation machinery currently used for woven plastic silt fence (control) installation. The third generation silt fence wool / burplap product was installed at locations 2 and 3 in June 2016 (Figure 2c) and was monitored in July 2016.

(a) First generation silt fence – pure wool, wet felted, batts stitched together in a continuous roll. August 2014.

(b) Second generation silt fence - 2 pure wool, wet felted layers from batts, plastic mesh in between the wool layers, and extra horizontal stitching. July 2015.

(c) Third generation silt fence-2 layers of burlap, with shredded wool in center, stitched together in continuous roll. June 2016.

(d) Woven plastic silt fence (control). July 2015.

Figure 2. Three generations of wool silt fence and the standard woven plastic silt fence tested in field trials, 2014 – 2016.

3.2 Wool Erosion Control Blankets and Compost on Highway 287

As an outcome of Task 2, a variety of the most promising woolen materials were selected for field tests (Table 2, Ament et al. 2016a). A field site on a roadside cut slope along U.S. Highway 287 (45°56’12.5959 N; 111°35’48.9750 W) near Three Forks, MT was selected for the wool ECB and wool compost field test site (Figure 1). This site was selected because it was a recently constructed highway project that failed to successfully revegetate after drill seeding in 2003 after construction. The slope is west facing and approximately 3H:1V slope.

Table 2: Treatments tested in experimental plots along U.S. Highway 287, Three Forks, MT.

Treatment Number	Descriptions of Experimental and Control Treatments	Product Developer
1	Carded Wool Blanket (73 g/m^2; 2 oz/yd^2)	Thirteen Mile Lamb and Wool Company
2	Carded Wool Blanket (44 g/m^2; 1 oz/yd^2)	Thirteen Mile Lamb and Wool Company
3	Needle punched (one pass) felted wool blanket	Brookside Woolen Mill
4	Needle punched (four pass) felted wool blanket	Brookside Woolen Mill
5	Compost with cut wool; 40:1	Mix of Mountain West Product's Glacier Gold + Brookside Woolen Mill cut wool
6	Control: standard 70% straw / 30% coconut ECB	Ero-Guard, Inc.
7	Control: Compost	Mountain West Products' Glacier Gold
8	Control: Broadcast seed only	N/A
9	Control: no seed or treatments	N/A
10	100% wool ECB	Ero-Guard, Inc.
11	50% wool / 50% straw ECB	Ero-Guard, Inc.

Eleven treatments were field tested at the U.S. Highway 287 field site including carded wool blankets, needle punched wool blankets, wool/straw ECBs, cut wool with compost, and controls. Prior to plot establishment, the site was sprayed with glyphosate (Roundup®) to remove all existing vegetation (sparse seeded and non-seeded plants) and raked to improve seed-to-soil contact.

Treatments, except for treatments 10 and 11 (Table 2), were arranged in a randomized complete block design with eleven replications of each treatment (Table 3; Figure 3). The eleven replications of treatments 10 and 11were added to the north end of the field site because the material arrived at a later date and was not part of the original experimental design. The treatment installation dates varied due to delays in product manufacturing and shipping. Treatments 1, 2, 5, 6, 7, 8 and 9 were installed October 17, 2014. Treatment 3 was installed on November 5, 2014, and treatments 4, 10 and 11 were installed on May 7, 2015. Treatment plots were 1 m^2 (10.2 ft^2) with 0.5 m (1.6 ft) spacing between plots. Each treatment plot was held in place using a 1 x 1 cm (0.4 in) gauge biodegradable coconut netting and secured with steel sod staples. Seeding took place at the time of treatment installation using a standard MDT seed mix (Table 4). Glacier Gold® compost was used and the compost with wool was weighed and mixed by the research team. The compost and compost with wool was applied at a 1.3 cm (½ in) depth as recommended by a previous MDT research project (Ament et al. 2011).

Table 3. Randomized block design of eleven treatments (see Table 2) replicated eleven times at U.S. Highway 287 field site.

11	11	10	2	6	5	5	8	2	9	7	3	4	8
11	11	10	4	3	7	7	1	3	6	3	6	5	6
10	11	10	7	5	1	9	7	8	1	1	1	1	2
10	11	10	9	9	4	8	4	4	7	5	8	7	1
	11	10	6	8	3	1	6	1	5	8	7	6	9
	11	10	8	4	9	4	3	6	8	9	9	2	5
	11	10	3	7	8	6	9	9	4	6	4	8	3
	11	10	1	2	6	3	5	7	2	2	5	9	4
	11	10	5	1	2	2	2	5	3	4	2	3	7
All replications for Treatments 10 & 11			Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11
U.S. Highway 287 ROW													

Table 4. Seed mix used for U.S. Highway 287 and Transcend experimental test plots.

Common Name	Scientific Name	Seeds/lb	Rate (PLS lbs/acre)	Seeds/ft^2	Percent of Mix	rate: g/m^2
Sheep Fescue	*Festuca ovina*	680,000	2.5	39	29%	0.28
Thickspike wheatgrass	*Elymus lanceolatus spp lanceolatus*	154,000	2.5	9	29%	0.28
Canada wildrye	*Elymus canadensis*	115,000	2.5	6	29%	0.28
Canada Bluegrass	*Poa compressa*	2,500,000	1.25	70	14%	0.14
		Total	8.75	124	100%	0.98

Figure 3. Experimental layout of eleven treatments with eleven replications at the Highway 287 field site, October 2014 (treatments installed in 2015 not pictured).

Vegetative canopy cover, defined as the vertical projection of the crown or shoot area of a species projected on the ground as a percent of the reference area (Mueller-Dombois and Ellenburg 1984), was recorded by species in September 2015 and July 2016. Photographs of the field site and treatment plots were taken during each field event. In addition, one composite soil sample was collected to analyze baseline nutrient content of the Highway 287 field site. Soil erosion was not measured at Highway 287 site because the treatments did not cover the entire length of the slope; therefore, erosion may have been influenced by other up-slope conditions and gaps between plots.

Species were grouped as seeded native grasses, desired non-seeded grasses and forbs (including the 2003 seeded species), and weeds for statistical analysis. Seeded grasses consisted of the four native species seeded for this experiment (Table 4). The desired non-seeded grasses and forbs group consisted primarily of species that may have been previously present on the site and re-established, or species that colonized the site which provide cover and soil stability. Desired non-seeded species primarily consisted of western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Nassella viridula*), and yellow sweetclover (*Melilotus officinalis*). The weeds were primarily kochia (*Kochia scoparia*), tumble mustard (*Sisymbrium altissimum*), annual brome grasses (*Bromus* spp.), and Russian thistle (*Salsola tragus*).

To determine effects of woolen and control ECB treatments on plant canopy cover, we conducted pairwise t-tests between the respective means, separately for each plant group. We applied Bonferroni corrections to account for multiple testing (Miller 1981). Plant canopy cover values were arcsine-transformed prior to analysis to meet t-test assumptions such as normality of data distribution, adequacy of sample size, and equality of variance in standard deviation. To determine if wool added to compost affected plant canopy cover, we conducted t-tests between the compost with wool and compost alone (control) treatment for each of the three plant groups. Plant canopy cover values were arcsine-transformed prior to analysis to meet t-test assumptions. Nontransformed means are presented for ease of data interpretation.

3.3 Wool Erosion Control Blankets at Transcend

A constructed test slope as WTI’s Transcend test facility located near Lewistown, MT (Lat. 47˚01’48.19” N, Long. 109˚28’15.75” W) was used as a second field test site for evaluating the wool / straw ECBs and the straw / coconut ECB as the control (Figure 4). The test slope at Transcend is a 2H:1V (2 horizontal:1 vertical) slope and is comprised of local subsoil. The slope dimensions are 100 m (328 ft) long and 5 m (16.4 ft) high. Soils were tested for nutrient content after construction of the test slope in 2013.

Figure 4. Test slope (2H:1V) constructed at Transcend, a WTI-MSU experimental station in Lewistown, MT.

Prior to plot establishment, the entire slope was sprayed twice (May and early June 2015) with a 6% glyphosate (Roundup®) solution to remove all existing vegetation. The test site was then hand-weeded and raked prior to seeding and installing the ECBs. On June 23 and 24, 2015, the slope was seeded using the standard MDT seed mix (Table 4) and six ECB treatments were installed on the test slope (Table 5 and Figure 4). Treatments were arranged in a randomized block design with ten replications. Each treatment plot was 1.5 m wide by 5 m long to cover the height of the slope (Figure 5). Treatment plots were placed on the south facing slope (azimuth 180 degrees).

Table 5. The six ECB treatments tested at the Transcend field site.

Number	Treatment[1]
1	Control A: No ECB
2	Control B: Standard 70% Straw / 30% Coconut ECB
3	100% Wool ECB
4	40% Wool / 60% Straw ECB
5	25% Wool / 75% Straw ECB
6	55% Wool / 45% Straw ECB

[1] The control and wool/straw ECBs were produced by Ero-Guard Inc.

Figure 5. One replication of the six treatments at the Transcend test slope.

Vegetative canopy cover was recorded by species in October 2015 and July 2016 at the Transcend field site. Photographs of the field site and treatment plots were taken during construction and each sampling event. Soil erosion will be measured at the completion of the field study (2017) when the ECBs are removed and the underlying rills and gullies can be assessed for density and size.

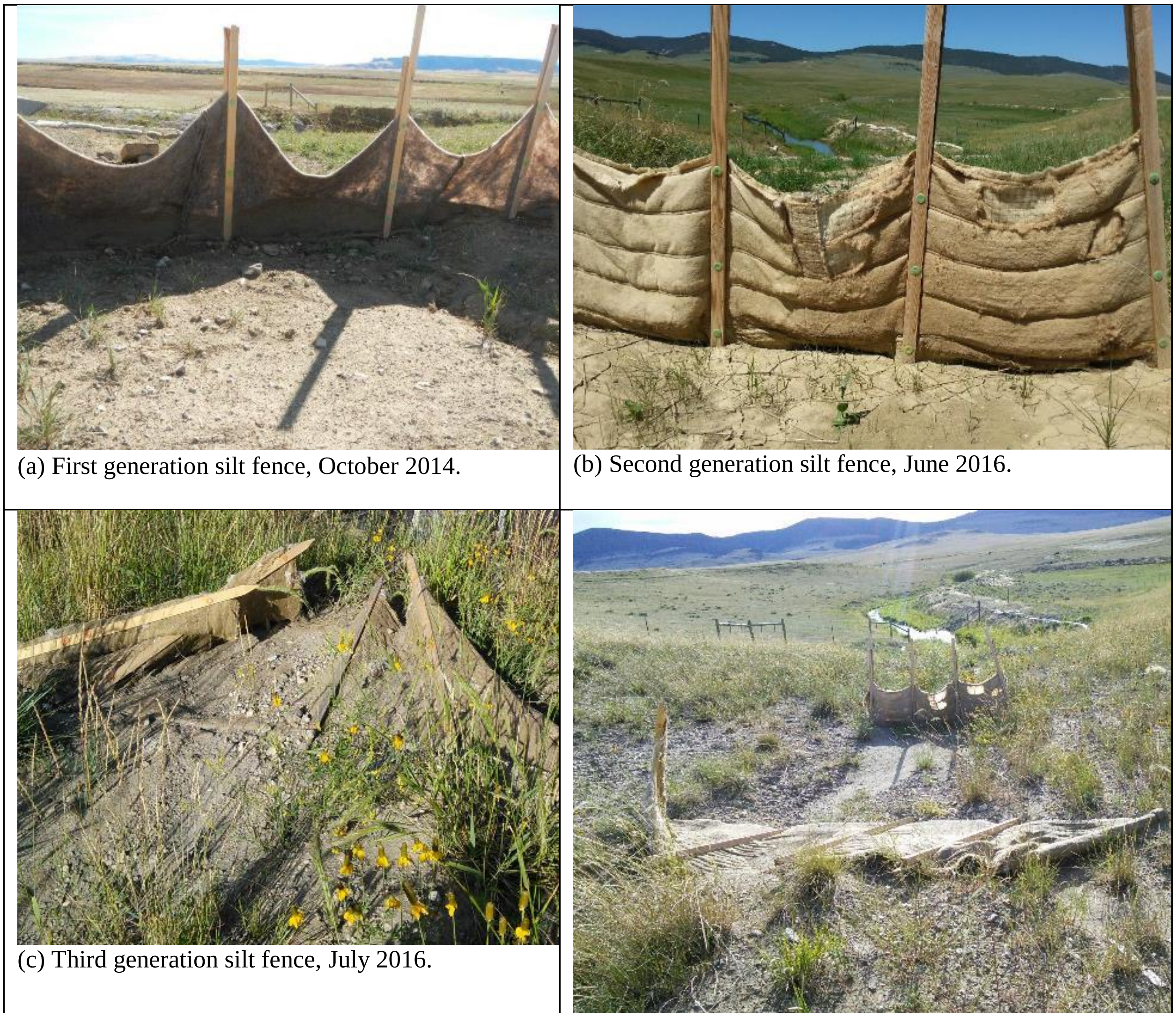
Species were grouped as seeded native grasses, desired non-seeded grasses and forbs, and weeds for statistical analysis. Seeded grasses consisted of the four native species seeded for this experiment. The desired non-seeded grasses and forbs group consisted primarily of species that naturally colonized the site from the surround area and provide cover and soil stability. Desired non-seeded species primarily consisted of smooth brome (*Bromus inermis*), witchgrass (*Panicum capillare*), and white sweetclover (*Melilotus alba*). The weed species were primarily field bindweed (*Convolvulus arvenis*), kochia (*Kochia scoparia*), prickly lettuce (*Lactuca serriola*), annual brome grasses (*Bromus* spp.), and alyssum (*Alyssum desertorum*).

To determine the effects of wool and control ECB treatments on plant canopy cover, we conducted pairwise t-tests between the respective means, separately for each plant group. We applied Bonferroni corrections to account for multiple testing (Miller 1981). Plant canopy cover values were arcsine-transformed prior to analysis to meet t-test assumptions such as normality of data distribution, adequacy of sample size, and equality of variance in standard deviation. Non-transformed means are presented for ease of data interpretation.

4 RESULTS AND IMPLEMENTATION

4.1 Silt Fence

The October 2014 observation of first generation silt fence found that it was able to capture sediment and filter water (Figure 6a). However, all four locations of the first generation wool silt fence were beginning to lose form – sagging, small holes – probably due to wetting events. This was a pure wool fence which was felted, thus had no additional strengthening materials. It appeared that it would not be able to survive intact, and fully functional, for two years. It indicated that future wool silt fence products needed additional inputs – stitching, mesh, etc. – to increase tensile strength and longevity. The first generation silt fence was removed in June 2015.



(a) First generation silt fence, October 2014.

(b) Second generation silt fence, June 2016.

(c) Third generation silt fence, July 2016.

(d) Third generation (foreground) and second generation (background) silt fence, July 2016.

Figure 6. Photo monitoring the three generations of wool silt fence developed and tested in field trials along U.S. Highway 12, 2014 – 2016.

The second generation silt fence maintained its form one year after installation (Figure 6b). The additional stitching and mesh netting reinforcement strengthened the wool silt fence and extended its functional life. After enduring several summer thunderstorm events in 2015, there was visual evidence it was fully successful in filtering water and containing sediment. However, parts of the second generation silt fence were beginning to biodegrade one year after installation, exposing mesh netting or creating small holes in the fabric, indicating that it could function as a short-term roadside reclamation product. This version of wool silt fence lacked the durability needed for multi-year roadside projects.

The two locations where the third generation silt fence was installed were monitored one month after installment. These burlap and wool silt fences were found lying on the ground with signs of a heavy rain and storm event that covered the fence with sediment and debris (Figure 6c and 6d). While the third generation silt fence did not withstand the storm event, the two remaining second generation silt fences remained in place and were functioning. It appears two layers of burlap and a layer of wool may be too restrictive to water flow during storm events. It appears that this product, although easily produced with existing ECB manufacturing equipment, will need further development that adjusts the amounts of burlap and wool content.

4.2 Wool Erosion Control Blankets and Compost on Highway 287

Soil nutrient content for the Highway 287 field site is presented in Table 6. Soil pH, electrical conductivity (EC), sodium adsorption ratio (SAR), and organic matter (OM) were within recommended ranges for establishing native grasses (Table 6). Potassium (K) levels were over twenty times the recommended ranges. Phosphorous (P) and the form of nitrogen available for plant growth (NO_3) were below recommended nutrient ranges for establishing native grasses (Table 6). Thus, the Highway 287 site is nutrient poor for the two important macronutrients for plant establishment and growth. However, selecting a harsh site (i.e. nutrient poor, arid) was an objective of the study design in order to determine if wool products can improve plant establishment in challenging conditions.

There were no significant differences of treatment effects on mean plant canopy cover in 2015. In 2016 significant differences were observed reflecting differences in mean canopy cover by the different plant groups after two growing seasons (Table 7). Pairwise t-tests were used to determine whether the mean canopy cover of each treatment, for each plant group, were statistically different from one another. That is, the t-tests compared one treatment to one other treatment with all combinations of treatments assessed (see Table 8 and Table 9). P-values that are less than 0.05 are used to determine when the treatments differ, that the difference is not due to random chance but can be attributed to the treatment (P-values > 0.05 indicate that the differences in the two treatments being compared are likely to occur by random chance). Tables 7 and 8 provide P-values for significant differences in seeded species and weed species canopy cover for ECB products. No table was created for the P-values for compost versus compost with cut wool treatments, instead the P-values are in the text.

Table 6. Soil nutrient values on the U.S. Highway 287 and Transcend test sites.

Analysis[1]	Soil		
	Hwy 287 Soil	Transcend Soil	Recommended Range[2]
pH	7.7	7.9	5.5 -8.5
EC (dS/m)	3.1	0.7	< 8
SAR (unitless)	5.8	-	< 12
Ca (mg/L)	379	3.5	-
Mg (mg/L)	29	2.4	-
Na (mg/L)	434	0.5	-
OC (%)	1.6	-	-
OM (%)	2.8	1.7	2
K (mg/kg)	2,770	150	75 - 125
P (mg/kg)	3.0	7 .0	5 - 13
NO_3, (mg/kg)	8.0	4.0	17 - 30
N-Total (%)	0.3	-	-

[1] EC = electrical conductivity; SAR = sodium adsorption ratio; Ca = calcium; Mg = magnesium; Na = sodium; OC = organic carbon; OM = organic matter; K = potassium; P = phosphorous; NO_3 = Nitrate; N = nitrogen; C:N = carbon to nitrogen ratio; dS/m=deciSiemen per meter; mg/L = milligrams/liter; mg/kg = milligrams/kilogram.
[2]Recommended range from Colorado State University Soil Testing Laboratory.

Table 7. Mean percent canopy cover of plant groups by treatments at Highway 287 test site.

Treatment	Description	Mean Percent Canopy Cover (%)		
		Seeded Native Grass	Desired Non-Seeded Species	Weed Species
1	Carded Wool Blanket (73 g/m^2; 2 oz/yd^2)	8.6	3.2	17.8
2	Carded Wool Blanket (44 g/m^2; 1 oz/yd^2)	9.7	4.5	21.5
3	Needle punched (one pass) felted wool blanket[2]	15.1	3.2	20.4
4	Needle punched (four pass) felted wool blanket	2.9	2.0	24.3
5	Compost with cut wool; 40:1	10.2	1.7	39.1
6	Control: standard 70% straw / 30% coconut ECB	4.7	5.0	17.7
7	Control: Compost	6.4	1.3	35.4
8	Control: Broadcast seed only	0.9	2.9	47.1
9	Control: no seed or treatments	0.9	3.5	49.8
10	100% wool ECB	20.9	1.4	10.8
11	50% wool / 50% straw ECB	24.6	2.1	13.6

[1] Treatment 1&2: Thirteen Mile Lamb and Wool Company; Treatment 3&4: Brookside Woolen Mill; Treatment 5: Mountain West Product's Glacier Gold + Brookside Woolen Mill cut wool; Treatment 6,11,&12: Ero-Guard, Inc.; Treatment 7: Mountain West Product's Glacier Gold
[2]Treatment is missing two replications due to lack of material.

Seeded grass establishment ranged from 0.9% to 24.6% canopy cover after two growing seasons with the broadcast seed and no seed controls having the lowest seeded species establishment and the 50% wool / 50% straw ECB having the highest percent cover (Table 7). In general, the three controls had significantly lower seeded grass canopy cover than all the wool treatments except the four-pass needle punch blanket (Tables 7 and 8). T-test comparisons of wool ECBs found the 100% wool and 50% wool / 50% straw treatments to have significantly greater seeded grass cover than both carded wool blankets and four pass needle punch blanket treatments. The compost with cut wool did not have significantly greater seeded grass cover than compost alone ($P = 0.137$).

The amount of **desired non-seeded species** that re-established on the treatment plots was low, ranging from 1.3 – 5.0 percent canopy cover. The canopy cover of desired non-seeded species did not significantly differ for any ECB treatment ($P = 1.0$ for all t-tests). In addition, desired non-seeded species canopy cover did not differ on the compost with wool compared to the compost control ($P = 0.504$). Therefore, species re-establishing or colonizing the site which provide canopy cover and soil stability were relatively evenly distributed on the study site.

Weed species established on the treatment plots at mean canopy covers of 10.8% to 49.8% (Table 7). Weed canopy cover was greater than seeded species canopy cover in all treatments except the 100% wool and 50% wool / 50% straw ECB treatments which had greater canopy cover of seeded grasses. Wool treatments did not differ significantly in the weed canopy cover ($P = 1.0$ for all t-tests). The only significant differences in the amount of weed cover was in comparison to the control. The straw / coconut control had significantly less weed cover (17.7%) than the seed only (47.1%; $P = 0.019$) and no seeding (49.8%; $P = 0.007$) controls. The seed only control also had significantly greater weed cover than the 73 g/m^2 carded wool blanket, 100% wool ECB, and 50% wool / 50% straw ECB treatments (Table 8). Similarly, the no seeding control had significantly greater weed cover than all treatments except the four-pass needle punch treatment. The compost with cut wool did not have significantly greater weed canopy cover than compost alone ($P = 0.635$).

Table 8. P-values generated from independent t-tests of mean *seeded* species canopy cover between ECB treatments. Significant values (< 0.05) highlighted for interpretation. See Table 7 for mean values.

TREATMENTS[1]	T 6: Control: 70% straw/ 30% coconut	T 8: Control: Seed only	T 9: Control: No seeding	T 1: Carded Wool (73 g/m^2)	T 2: Carded Wool (44 g/m^2)	T 3: Needle punch (1 pass)	T 4: Needle punch (4 pass)	T 10: 100% wool	T 11: 50% wool / 50% straw
T 6: Control: 70% straw / 30% coconut	-	-	-	-	-	-	-	-	-
T 8: Control: Seed only	0.079	-	-	-	-	-	-	-	-
T 9: Control: No seeding	0.050	1.000	-	-	-	-	-	-	-
T 1: Carded Wool (73 g/m^2)	1.000	0.000	0.000	-	-	-	-	-	-
T 2: Carded Wool (44 g/m^2)	1.000	0.000	0.000	1.000	-	-	-	-	-
T 3: Needle punch (1 pass)	0.002	0.000	0.000	0.663	1.000	-	-	-	-
T 4: Needle punch (4 pass)	1.000	1.000	1.000	0.058	0.031	0.000	-	-	-
T 10: 100% wool	0.000	0.000	0.000	0.001	0.002	1.000	0.000	-	-
T 11: 50% wool / 50% straw	0.000	0.000	0.000	0.000	0.000	0.244	0.000	1.000	-

[1] Manufacturers: Treatment 1&2: Thirteen Mile Lamb and Wool Company; Treatment 3&4: Brookside Woolen Mill; Treatment 6, 10 &11 Ero-Guard, Inc.

Table 9. P-values generated from independent t-tests of mean *weed* species canopy cover between ECB treatments. Significant values (< 0.05) highlighted for interpretation. See Table 7 for mean values.

TREATMENTS[1]	T 6: Control: 70% straw/ 30% coconut	T 8: Control: Seed only	T 9: Control: No seeding	T 1: Carded Wool (73 g/m²)	T 2: Carded Wool (44 g/m²)	T 3: Needle punch (1 pass)	T 4: Needle punch (4 pass)	T 10: 100% wool	T 11: 50% wool / 50% straw
T 6: Control: 70% straw / 30% coconut	-	-	-	-	-	-	-	-	-
T 8: Control: Seed only	0.019	-	-	-	-	-	-	-	-
T 9: Control: No seeding	0.007	1.000	-	-	-	-	-	-	-
T 1: Carded Wool (73 g/m²)	1.000	0.025	0.010	-	-	-	-	-	-
T 2: Carded Wool (44 g/m²)	1.000	0.061	0.024	1.000	-	-	-	-	-
T 3: Needle punch (1 pass)	1.000	0.061	0.026	1.000	1.000	-	-	-	-
T 4: Needle punch (4 pass)	1.000	0.404	0.183	1.000	1.000	1.000	-	-	-
T 10: 100% wool	1.000	0.000	0.000	1.000	1.000	1.000	1.000	-	-
T 11: 50% wool / 50% straw	1.000	0.001	0.000	1.000	1.000	1.000	1.000	1.000	-

[1] Manufacturers: Treatment 1&2: Thirteen Mile Lamb and Wool Company; Treatment 3&4: Brookside Woolen Mill; Treatment 6, 10 &11 Ero-Guard, Inc.

4.3 Wool Erosion Control Blankets at Transcend

Soil tests for the Transcend site indicate a slightly basic soil with relatively low nutritional values of micronutrients (Table 6). Soil pH, and EC were within recommended ranges for establishing native grasses. Soil organic matter and nitrate were lower than recommended ranges. Potassium levels were higher, and phosphorous levels were within recommended ranges for establishing native grasses. The Transcend site is a low nutrient site. However, selecting a harsh (i.e. nutrient poor, arid) site was an objective of the study design in order to determine if woolen products can improve plant establishment in these environments.

The Transcend site was seeded in late June and monitored in October 2015. Seeded species did not establish during this period; therefore, the 2015 results are not presented. The Transcend site will be sample again in 2017 and the results presented in the Final Report. We present here results from 2016 reflecting mean canopy cover by plant groups after one full growing season (Table 10). Pairwise t-tests were used to determine significant differences among treatments within a plant group. Pairwise t-tests were used to determine significant differences between treatments within a plant group. That is, the t-tests compared one treatment to one other treatment with all combinations of treatments test assessed. P-values are used to determine when treatments differ. P-values > 0.05 indicate the two treatments compared are not significantly different (i.e. the canopy cover is the same for both treatments). There were no significant differences between treatments for any of the plant groups; P-values ranged from 0.229 to 1.0 for all t-tests (data not provided). Therefore, results suggest the canopy cover by plant group was the same for each of the six treatments.

Table 10. Mean percent canopy cover of plant groups by treatments at Transcend test site.

Treatment[1]	Description	Mean Percent Canopy Cover (%)		
		Seeded Native Grass	Desired Non-Seeded Species	Weed Species
1	Control A: Seed only (No ECB)	1.94	8.36	29.62
2	Control B: Standard 70% Straw / 30% Coconut ECB	4.74	3.10	31.76
3	100% Wool ECB	5.18	3.34	30.94
4	40% Wool / 60% Straw ECB	4.12	6.66	38.78
5	25% Wool / 75% Straw ECB	3.10	5.16	33.42
6	55% Wool / 45% Straw ECB	6.02	2.66	28.38

[1] Manufacturer: Treatment 2, 3, 4, 5 &6: Ero-Guard, Inc.

Seeded species had low canopy cover on all treatments after one growing season, ranging from 1.94% to 6.02%. The desired non-seeded species also had low canopy cover at 2.66% to 8.36%. Weed species were the dominant canopy cover on the treatments with 29.62% to 38.78% canopy cover. Treatments will be measured again in 2017 after two growing seasons.

5 CONCLUSIONS

5.1 Silt Fence

The second generation silt fence appeared to be the most durable and functional for capturing sediment. The wool felting provided an adequate medium for sediment filtration and the stitching improved strength and durability to last one year in field conditions. Future improvements of this product would include making the second generation silt fence 100 % biodegradable for decomposition on site. The plastic netting in the center of the wool material would need to be replaced with biodegradable fiber netting.

The third generation silt fence needs further development. Only two sections were installed for less than a month before they were blown over by a storm event. It is possible that one layer of wool between a layer of burlap and a layer of netting on the downstream side, may be a better fence that is not overly restrictive of water flow and yet sufficiently filters sediment and can be produced at scale with existing ECB manufacturing equipment. The third generation silt fence will continue to be monitored in 2017.

5.2 Wool Erosion Control Blankets and Compost along Highway 287

In general, the three control treatments (standard 70% straw / 30% coconut ECB, seed only, no seed) had significantly lower seeded grass canopy cover than all wool treatments except the four-pass needle punch ECB. This suggests that the wool material, regardless of type, may be providing some benefit to seeded grass during establishment. Non-seeded desired species established in relatively equal proportions among treatments which is probably a benefit of the randomized complete block design. Thus, conclusions are based on comparing the various treatments' mean canopy cover of seeded species and weedy species.

5.2.1 Wool / Straw ECBs made by an ECB manufacturer

Seeded grass canopy cover

The two best performing treatments (i.e. greatest seeded grass establishment) were the rolled wool / straw ECBs produced by Ero-Guard, Inc. The 100% wool ECB and 50% wool / 50% straw ECB had the greatest mean seeded grass canopy cover with 20.9% and 24.9%, respectively, after two years (Table 7). These two ECBs were developed for the project and produced by traditional geotextile manufacturing machinery that creates ECB rolls. One square meter test sections were cut from the rolls and applied to the experimental plots. The mean seeded grass canopy cover was four to five times higher for these two wool ECBs than the standard 70% straw / 30% coconut ECB used by MDT, which had a seeded grass mean canopy cover of 4.7% after two growing seasons (Table 7). These canopy cover differences were statistically significant ($P < 0.0001$) for both wool ECBs compared to the standard straw / coconut ECB (Table 8).

The project demonstrated that rolled ECBs are important for re-vegetation. The 100% wool, 50% wool / 50% straw, and 70% straw / 30% coconut ECBs all had higher mean seeded grass canopy cover after two years than the no seed (0.9% cover) and seed only (0.9% cover) controls (Table 7). The 100% wool and 50% wool / 50% straw ECB treatments averaged greater than 20% canopy cover of seeded species within two years demonstrating how well the wool products performed at a site that previously failed to adequately establish vegetation after its construction in 2003. However, some caution should be used during data interpretation due to treatments being installed at different dates. Treatments 4, 10, and 11 were seeded and installed in May 2015 since the products hadn't been developed and delivered until that time. While all the other treatments were installed in fall 2014. The treatments installed in the fall experienced a high wind event and heavy erosion event that may have impacted seeded grass establishment. In addition, some research has indicated spring seeding produces higher seeded grass densities than fall seeding (Davis et al. 2016). Further testing of the woolen materials should occur when all treatments can be seeded and installed at the same time so weather and timing do not complicate the interpretation of results.

Weed canopy cover

In general, the two rolled wool ECBs made by Ero-Guard, Inc., and the standard straw / coconut ECB had lower weed canopy cover than seeded and non-seeded control treatments indicating that ECBs, regardless of the composition of their materials, provided some benefit in weed suppression. The mean weed canopy cover for 100% wool ECB, 50% wool / 50% straw ECB and 70% straw / 30%coconut ECB was 10.8%, 13.6%, and 17.7%, respectively (Table 7). However, these weed canopy cover values were not significantly different ($P = 1.0$; Table 8). However when any of the mean weed canopy cover of these ECBs were compared to the no seed control (49.8%) or the broadcast seed control (47.1%), the differences were significant, with P-values varying from 0.0 to .019 (Table 8).

Field observations found the wool in the ECBs became felted when exposed to the weather. The felted wool material may have provided a barrier for broadleaf plants while allowing narrower grass leaves to penetrate the wool ECBs. Weed species had higher canopy cover than seeded species on all treatments except the 100% wool and 50% wool / 50% straw ECB.

5.2.2 Wool ECBs made by Montana wool mills

There were four wool ECBs developed with Montana wool mills for the project (Treatments 1 – 4; Table 2). These products were made by Thirteen Mile Lamb and Wool Company and Brookside Woolen Mill as individual pieces or batts, by either carding at different weights or by felting the wool via a different number of passes through a needle punch machine. Each batt was made to be approximately one square meter. All four of these test products were made of pure (100%) wool.

Seeded grass canopy cover

Three of the four pure wool ECB treatments had greater mean seeded grass canopy cover than the standard 70% straw / 30% coconut ECB. The standard ECB had 4.7% cover while the 44 g/m^2 and the 73 g/m^2carded wool ECBs had 9.7% and 8.6% seeded grass cover, respectively, and single pass needle punch ECB had 15.1% cover. However, the only product statistically different than the standard ECB was the single pass needle punch ECB ($P = 0.002$). The results suggest these wool products offered advantages for seed establishment and growth when compared to the standard straw-coconut ECB.

Weed canopy cover

In general, ECB treatments, including the standard straw / coconut ECB, at Highway 287, had lower weed canopy cover than the seeded and non-seeded control treatments indicating that the 4 different materials – no matter which type - provided some benefit in weed suppression.

All four wool ECBs had higher mean canopy cover for weedy species, 17.8%, 21.5%, 20.4% and 24.3%, then the standard straw / coconut ECB, 17.7% (Table 6). However, differences between these wool ECBs and the standard straw/coconut ECB weed cover were not statistically significant.

Field observations found the wool ECBs made from Montana wool mills became felted and shrank when exposed to the weather, most likely due to the wetting from precipitation - rain and snow - and the subsequent drying of the wool fibers. The felted wool material may have provided a barrier for broadleaf plants while allowing narrower grass leaves to establish through the wool material. Furthermore, weed presence may have impacted the seeded grass species' ability to establish.

5.2.3 Cut wool pieces mixed with compost

There was no statistical difference in the mean canopy cover of seeded grass species of the compost treatment (control) compared to the cut wool with compost treatment, 6.4% and 10.2%, respectively (Table 7). Similarly, no statistically significant differences were found for mean canopy cover of weeds or desired non-seeded species between the two treatments. This indicates that the project could not determine that cut wool pieces provided a benefit to the compost material.

5.3 Wool Erosion Control Blankets at Transcend

The seeded species were present on all treatment with low canopy cover after one growing season. The desired non-seeded species also had low canopy cover and were relatively evenly distributed between treatments so should not influence the results of seeded species establishment. Weed species were the dominant canopy cover on the treatments and may be interfering with seeded species establishment.

The Transcend treatments were all seeded and installed at the same time which eliminates any bias for treatments that did not undergo the same weather events. Seeded grass should continue to develop and monitoring the site again in 2017 may provide a better indication of how well the treatments establish seeded grasses and compare to each other. Weed management should be considered for the experimental site. By controlling weed species, seeded grass establishment may improve. The treatments at Transcend cover the slope from top to bottom and can be used to measure erosion within each treatment in 2017. After an additional vegetation monitoring event (summer 2017), treatments would be removed and erosion indicators measured. The 2017 monitoring at Transcend will be presented in the project Final Report.

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