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RESEARCH REPORT

Evaluating Erosion Control Blankets Made with Waste Wool along Southeastern Idaho Roads

RP 277

By

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16. Abstract

This project sought to determine whether erosion control blankets (ECBs) using wool instead of coir (coconut fibers) on two different roadside cut slope restoration projects in southern Idaho increased seeded native species establishment in cheatgrass dominated sites. By the second growing season, results for some wool ECBs showed great promise in supporting native perennial grass establishment and growth. Unfortunately, after three growing seasons, the study results were inconclusive due, in large part, to a drought during the final growing season in 2021. An analysis of the wool in the ECBs describes their ability to provide significant amounts of nitrogen (N) for plant growth for three growing seasons as the wool decomposes. A cost benefit analysis demonstrates that, depending on the amount of wool used in the ECB, it may be less expensive to use wool ECBs than to fertilize and cover with traditional coir ECBs in non-weedy nitrogen poor cut slopes.

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Technical Advisory Committee

Each research project is overseen by a Technical Advisory Committee (TAC), which is led by an ITD project sponsor and project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

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Executive Summary

This research project constructed two random-block experiments along two Idaho Transportation Department highways in District 5, Interstate Highway 86 near Chubbuck and US Highway 30 near McCammon. The test design enabled researchers to examine the establishment and growth between different vegetative groups: native perennial grasses in the seed mix, weedy forbs, weedy grasses, and other species, those not in the seed mix and not weeds. Using different ratios of wool and straw in the matrix of the erosion control blankets (ECBs), four different wool ECBs were compared to the current typical coconut-straw ECB used by transportation agencies for roadside vegetation reestablishment after construction, and for other types of roadside disturbances. Wool has high water retention capabilities and contains 17% nitrogen, an important macronutrient for plants.

During each of three growing seasons, the vegetative canopy cover of all species in the sampling quadrats of each experimental plot was measured, summarized, and evaluated to determine if there were any differences in the performance of the different types of wool-straw ECBs, the coconut-straw ECB and the control plots that were not covered by ECBs.

Differences in mean percent canopy cover of seed mix species and weedy species, under different wool ECBs as well as the control plots across the three growing seasons did not achieve statistical significance. Some wool ECB treatments had large increases (up to 20-fold) in seed mix species mean percent canopy cover between Year 1 and Year 2; thus, some of the wool ECBs showed great promise. Further increases were expected between Year 2 and Year 3. However, three dry three months leading up to the third growing season's (2021) vegetative measurements decimated many of the seed mix seedlings that had established in the first two years. Thus, results are inconclusive as to whether wool ECBs increase the establishment of seeded native perennial grasses in cheatgrass dominated ITD roadsides in southern Idaho compared to current practices using existing ECB materials.

Independent of the vegetative study, an analysis of the wool in the ECBs describes how it could provide significant amounts of nitrogen for plant growth, in lieu of commercial fertilizers, for cut slopes that are poor in nitrogen. Applications of nitrogen fertilizer are not recommended for native plant restoration in weedy locales because published research indicates weedy species often take advantage of nitrogen fertilization. Wool might provide managers another option. Due to wool's slow decomposition, unlike a single burst of nitrogen from the typical single application of a commercial fertilizer, nitrogen would be available in small amounts for up to three years for seeded native plant growth during the wool's slow decomposition.

From an economic perspective, for nitrogen-poor roadside reclamation sites with cut slopes requiring ECBs, if fertilization was being considered, it appears using some types of wool ECBs could be more cost effective. Instead of relying on applying nitrogen fertilizer and covering slopes with standard ECBs comprised of exotic fibers such as coir or other types of domestic natural fibers (e.g, hemp, wood strands), a wool ECB might more effectively address restoration needs.

1. Project Overview

Road construction and the development of source materials (e.g., gravel, fill) for roadbeds are activities central to the mission of the Idaho Transportation Department (ITD), but can result in severely damaged soils. ITD projects that disturb roadsides require reclamation plans to minimize surface runoff and soil erosion, to re-establish soil health, and to grow desirable vegetation for permanent stabilization. Establishing roadside vegetation is even more difficult given southern Idaho's dry climate. Annual, exotic (non-native) plants such as cheatgrass, *Bromus tectorum*, a grass prone to fire ignitions, germinate earlier than most of the native grass and forb species typically used in ITD seed mixes. This allows cheatgrass to out-compete seeded and other native plants for spring moisture and nutrients, particularly in arid and semi-arid environments. In addition to cheatgrass, many Idaho roadsides can become infested with exotic forb species as well, such as kochia, *Kochia scoparia*, or Russian thistle, *Salsola iberica*. Even in roadside plant communities without intense competition from exotics, seeded and native plants can struggle to establish under low precipitation. For example, sparse rains may not coincide with the emergence of young, small, vulnerable seedlings.

An array of erosion control products is available for deployment as part of ITD roadside reclamation and slope stabilization projects. These products are typically used on slopes greater than 3:1 (vertical to horizontal, equivalent to 33.5 % or 18-degree slopes), often in combination with various site preparation techniques and seedings and/or plantings. Traditional erosion control products currently available on the market use fibers from coconut (coir) and other tropical plants (e.g., jute, sisal) which must be imported from southern Asia or other tropical parts of the globe. None of these fibers are shown to be particularly helpful in moisture retention. Other products are made from woven plastic or use other synthetic materials, which may break into small pieces but do not truly biodegrade. All these standard erosion control products have been used for decades with few options, particularly for applications in challenging roadside environments. More recently, domestic hemp materials have been developed and are now commercially available for erosion control.

This project sought to determine if the incorporation of wool fibers into erosion control blankets (ECBs) was beneficial and cost effective in restoring vegetation on roadside cut slopes in southeast Idaho. Research has shown that pure wool fiber can store up to 400% of its weight in water, which is much better than rock wool (synthetic mineral product) or coir (Upton 2003). This may give erosion control blankets (ECBs) using waste wool a decided advantage in harsher, drier climates. In addition, sheep wool contains up to 17% nitrogen and can act as a slow-release fertilizer for plant growth as it decomposes. Research from Europe evaluating the use of woolen fabrics for green roof applications demonstrated a strong beneficial plant growth response from wool in comparison to coir (Herfort 2010).

An initial investigation was led by the Western Transportation Institute at Montana State University (WTI) to explore the use of waste wool (wool of insufficient quality to be used in textiles) in roadside reclamation and erosion control products for the Montana Department of Transportation (MDT). The project expanded with funding from the Center for Environmentally Sustainable Transportation in Cold

Climates, United States Department of Transportation (USDOT) University Transportation Center (UTC) housed at the University of Alaska, Fairbanks. The final report from the jointly funded project was issued in December 2017 (Ament et al. 2017).

The most promising products from the Montana study were ECBs using various ratios of wool produced in a commercial manufacturing plant in Minnesota using the same machinery that produces traditional ECBs for transportation agencies and others. In a roadside experiment where plant establishment by MDT had previously failed, seeded mean plant canopy cover was 4-5 times higher under two different types of wool-straw ECBs when compared to the standard coconut-straw ECB that MDT traditionally uses. At the same highway site, weed establishment was lower in the plots with the wool ECBs than in those under the standard coconut-straw ECBs, although these differences were not statistically significant (Ament et al. 2017). These and other promising results from this initial study indicate that ITD roadsides, particularly in some of the more challenging environments, may also benefit from these prototype woolen-based products.

The use of these new woolen ECBs might lead to better results for ITD roadside cut slope reclamation given the challenges, particularly in the drier, harsher environments in the southern portion of the state. ITD road construction and maintenance projects can severely disturb roadside slopes, soils, and plant communities. Such disturbance, if not properly and immediately addressed can have a suite of adverse effects on roadsides:

- The proliferation of noxious weed populations and seeds.
- The creation of unstable roadside slopes, which may affect the safety of motorists, impair function of roadway facilities, and impose on ITD maintenance program budgets.
- The potential for soil loss, soil erosion, and siltation into adjacent water bodies
- The loss of habitat for pollinators and other valuable native species.

This ITD research project was developed to explore these prototype ECB woolen products in field settings and compare their performance with an existing commercially available erosion control product using coir fibers to determine the woolen products suitability for roadside application and installation. The project evaluated performance and relative cost effectiveness of the wool ECBs against an existing commercially available coir ECB product. The test sites are located along two roadsides in the semi-arid climate of ITD District 5 based near Pocatello in southeastern Idaho.

2. Key Properties of Wool

The benefits of incorporating waste wool in ECBs is predicated on two principal facets of this material; it is composed of a significant amount of nitrogen (Simpson and Crawshaw 2002), and it helps retain moisture. Thus, roadside reclamation products containing wool may have advantages not shared by current commercially available ECBs which contain straw and coir. Other ECB products using alternative materials (e.g., hemp, wood strands) are also being developed; their water retention capabilities and chemical composition have not yet been reported in the literature.

Fertilizer pellets using wool for gardening are reported to hold up to 20% of their weight in water (Wild Valley Farms, 2021). Wool that is scoured – a process to remove dirt, feces, lanolin, weed seeds, and other impurities, via a series of hot baths – can store up to 400% of its weight in water (Upton 2003). When scoured wool absorbs water greater than 33% of its weight, the moisture is available for plant growth (D'Arcy, 1990).

Pure sheep wool contains 16% to 17% nitrogen (Simpson and Crawshaw, 2002) and as it decomposes, it can act as a slow-release fertilizer for plant growth (Zheljazkov, 2005). Since nitrogen is a key component of wool, technologies are being developed that seek to turn waste wool into nitrogen fertilizer in Europe (Zoccalo et al., 2015).

Three horticultural experiments demonstrated that nitrogen from waste wool could increase plant production in pots. An experiment that used waste wool as a soil amendment increased yields of two different agricultural leafy crop yields – swiss chard and basil – by 1.6 to 5 times greater compared to the unamended control, depending on the amount of wool incorporated (Zheljazkov et al., 2009). Similarly, for other horticultural crops, the use of waste wool increased crop yields up to 33% (Gorecki and Gorecki, 2010). Lastly, a study of four different herbs – basil, peppermint, sage, and thorn apple – found not only that wool increased plant production, but it also increased nitrogen in the potted soil (Zheljazkov, 2005).

A study in Germany using wool pellets indicated that they could be a viable replacement for fertilizer for vegetables (Bohme et al., 2012). Wool pellets are commercially available in the United States for horticultural application, an online search will return several commercial sources.

As a result of the nitrogen content and moisture retention capacity of wool, there have been some explorations of incorporating waste wool into products that promote plant establishment and growth, and to reduce erosion. A preliminary one-year study found that a geotextile rope using wool and other fibers could be staked sinuously across a slope and placed in a ditch to reduce erosion and to support vegetative growth (Broda et al., 2018). Wool that is intertwined with synthetic fibers into a rope was successfully used to stabilize and revegetate a cut slope along a road in Poland (Broda et al., 2020). As mentioned earlier, an experiment in Montana used wool pieces in erosion control blankets that, in some portions of the experiment, proved to increase vegetative cover significantly on a roadside cut slope in

(Ament et al., 2017). The promise of wool as a multifunctional medium to enhance roadside reclamation, has inspired this ITD research project.

3. Methodology

3.1 Experimental Design

Two highway roadside reclamation sites were selected in southeast Idaho in ITD's District 5 where a random block design (Dodge 2008) was set up for each highway's experimental site. Randomized block designs are used to minimize the effects of systematic error by trying to control the effects due to variations between the different blocks. A randomized block design has each of the experimental units placed in groups called blocks; for this project, the blocks are two highway roadside experimental sites.

There are 10 repetitions for each type of treatment within each of the blocks. The treatments are randomly allocated among each of the repetitions within each block. The size of each ECB or control treatment is a rectangle, 5 meters (m) by 1 m, hereafter referred to as the experimental plot. The short sides of the rectangle are the top and bottom of the plot, and the longer sides run parallel to the slope. A summary of the treatments is listed in Table 1.

Table 1. Experimental and control treatments tested in experimental plots.

Treatment Number	Descriptions of Experimental and Control Treatments	Abbreviation
1	Control: Bare soil only	B
2	Control: Bare soil with broadcast seed mix	BS
3	Control: 70% straw-30% coconut ECB over broadcast seed mix	CCBB
4	100% wool ECB over broadcast seed mix	100W
5	70% wool-30% straw ECB over broadcast seed mix	70W30S
6	50% wool-50% straw ECB and seed mix	50W50S
7	30% wool-70% straw ECB and seed mix	30W70S

To evaluate the relative effectiveness of the wool ECBs compared to the control experimental plots, the site preparation, seed mix, and seed rate were held constant for both highway experimental site locations. Controlling these site variables allowed for the experiment to measure vegetative canopy cover as the single dependent variable. Vegetative canopy cover is the value that was used to assess the relative effectiveness of the four different wool-straw ECBs and the three types of control treatments in Table 1.

The amount of rainfall and other environmental factors are relatively similar for all test plots at each roadside test site or block; however, environmental factors did vary between the two different highway locations.

Vegetative canopy cover was recorded for each species for each experimental plot. Then, the relative abundance of three groups of plants – seed mix species, weedy grasses, and weedy forbs – were summed for each experimental plot to use for performance analysis comparisons. A fourth group, other species, were recorded and measured, but ultimately were not analyzed since their contributions to canopy cover was minimal.

Although the canopy cover of each species was measured individually, their total mean canopy cover was summarized by plant grouping, and the mean canopy cover of the three groups, by treatment, were evaluated statistically. Plant canopy cover is defined as the vertical projection of naturally standing plants onto the ground as a percent of the reference area. So, for any reference area, such as test plots in this project, the total canopy cover can exceed 100% because plants can overlap when they grow in multiple canopy layers (University of Idaho, 2009).

3.2 Experimental Plot Construction

3.2.1 Materials

Materials for the experimental plots were procured from Ero-Guard, Inc., a manufacturer of erosion control products that supplied rolled woolen ECBs for the Montana Department of Transportation roadside experiments in 2014 (Ament et al. 2017). The seed mix was developed in collaboration with ITD's District 5 Senior Environmental Planner to ensure it contained native species suitable for ITD roadsides in the study area.

3.2.1.1 Woolen ECB Materials

Four different types of ECBs with varying wool-straw ratios for the fill were procured for the experimental testing. A roll of pure wool ECB was obtained in 2014 and used on one of the highway test sites for this project. In addition, a roll of coir-straw ECB, to be used for the control plots, was also obtained from the same manufacturer.

To ensure the wool-straw ratios requested were accurately manufactured by Ero-Guard, 10 samples of material from each type of wool-straw ECB were collected. Each sample was a 10 centimeter (cm) by 10 cm piece of material. The 10 cm by 10 cm samples were randomly collected from the different rolls of each ECB type. The pure wool was not sampled.

The wool and straw in each sample was separated by hand. Each sample's component of wool and straw was weighed on a commercial scale, Ohaus Adventurer SL Analytical Balance, which is accurate to the 0.1 milligram (mg) and measured to the tenth of one gram (g). This was subsequently converted into its English weight in ounces (oz). A summary of the three wool-straw ECBs and their actual ratios of wool to straw (by mean air dry weight) and the total mean weight of the fill per square meter (m^2) and square yard (yd^2) of ECB are summarized in Table 2.

Table 2. Summary of ECB products by weight for the three wool-straw combinations.

Product Label	Mean Weight Ratio (*n* = 10)[1]	Mean Wool Weight g/m^2 (oz/yd^2) and Confidence Interval	Mean Straw Weight g/m^2 (oz/yd^2) and Confidence Interval	Total Mean Fill Weight g/m^2 (oz/yd^2)
30% Wool 70% Straw	37 % Wool 63% Straw	82.1 ± 6.99 (2.89 ± 0.25)	140.3 ± 14.9 (4.95 ± 0.53)	222.4 (7.84)
50% Wool 50% Straw	48 % Wool 52 % Straw	102.7 ± 16.5 (3.62 ± 0.58)	112.5 ± 9.9 (3.97 ± 0.35)	215.2 (7.59)
70% Wool 30% Straw	65% Wool 35% Straw	168.6 ± 37.1 (5.95 ± 1.31)	91.4 ± 7.27 (3.22 ± 0.26)	205.7 (7.26)

[1] The ratio of the wool and straw were calculated by weight, not volume

Given the large size of the rolled ECB production machinery (Figure 1), the manufacturing of the different types (ratios) of wool-straw ECBs were no more than 7% different than the product's label (see Column 2, Table 2). The manufacturer can adjust the ratios of wool and straw fibers for the fill material of an ECB using the same machinery (Figure 2). This same machinery can also use different ratios of straw, coir, or other fibers as well. All the ECBs manufactured for this study use the same jute netting (Figure 3) on both sides of the fill material.

Figure 1. View of manufacturing machinery producing a rolled erosion control blanket at Ero-Guard, Inc. facility in Marshall, MN.

Figure 2. Machinery used to produce erosion control blankets at Ero-Guard, Inc. facilities.

Figure 3. Close up image of an erosion control blanket showing the straw and wool fill material under the jute netting.

3.2.1.2 Seed Mix

The WTI Team worked with ITD's District 5 Senior Environmental Planner to develop a native perennial grass seed mix typically used by ITD for its roadside reclamation projects suitable for the sites selected for this field experiment. Five native perennial species were selected for the seed mix (Table 3). Three of the species are bunchgrasses: Bluebunch wheatgrass (*Pseudoroegneria spicata*), Canby bluegrass (*Poa secunda*), and Bottlebrush squirreltail (*Elymus elymoides*). Two are rhizomatous or sod forming: Thickspike wheatgrass (*Elymus lanceolatus*) and Western wheatgrass (*Pascopyrum smithii*). WTI procured the seed mix from a native perennial plant seed producer, Bruce Seed, in Townsend, Montana.

The ideal seeding rate for four of the five native perennials selected for this project is between 20 and 25 seeds per linear foot if drilled, or per square foot if broadcast seeded in cultivated landscapes. For the smaller seeded Canby bluegrass, the recommended seeding rate is nearly twice as high at 42 seeds per square foot (USDA-NRCS 2013). The recommended seeding rate was approximately doubled given the lack of site preparation and harsh nature of the experimental sites (Table 3).

Table 3. Summary of native plant species seed mix.

Species	Scientific Name	Cultivar	Seeds per Pound	Seeding Rate (PLS lb/ac)	Seeds/ft^2	Percent of Mix	Seeding Rate (PLS g/m^2)
Canby's bluegrass	*Poa secunda*	Canbar	925,000	4.0	85	10	0.45
Bottlebrush squirreltail	*Elymus elymoides*	CRNG	192,000	10.0	44	10	1.12
Bluebunch wheatgrass	*Pseudoroegneria spicata*	Goldar	139,000	14.0	45	35	1.57
Thickspike wheatgrass	*Elymus lanceolatus*	Critana	152,000	14.0	49	30	1.57
Western wheatgrass	*Pascopyrum smithii*	Rosana	93,000	20.0	43	15	2.24
All	**All**	**All**	**Total:**	**62.0**	**266**	**100**	**6.95**

Table 3 abbreviations: lb = pound; PLS = pure live seed; ac = acre; ft = feet; % = percent; g = gram; m=meter

3.2.2 Site Selection

This experiment sought to determine the utility of woolen ECBs on harsh sites. Most Departments of Transportation have specifications that typically require ECBs on slopes of 3:1 or greater, and thus we sought slopes with grades of at least a ratio of three units of rise (vertical) to one unit of run (horizontal), which is most commonly expressed as slopes with a grade of 3:1 or greater.

Roadsides for this experiment were sought that were challenging for reclamation; having steep, south- or west-facing slopes and those that were dominated by cheatgrass, given this species often outperforms other species at post-construction highway reclamation sites in southern Idaho. We also sought experimental sites with few established native Idaho perennial plants. Two sites were selected along ITD highways near Pocatello, ID. Both sites were dominated by exotic species and contained relatively few individual native grasses and forbs.

The Interstate Highway 86 (I-86) location is in Chubbuck, Idaho (42°54'44.6652" N; 112°27'8.8776" W) near Highline Road at I-86 Milepost 62. The plots are located in the highway right-of-way south of the eastbound lanes (Figure 4). The experimental plots have an azimuth of 167° (southeast) on a slope that varies from a 32% slope on the western end of the plots to 42% slope on the eastern side. This location had an abundance of cheatgrass and exotic forbs, including kochia*,* tumble mustard, *Sisymbrium altissimum,* and musk thistle, *Carduus nutans* (Figure 5). In addition, the slope experiences erosion pressure due to storm water run-off draining from the interstate surface.

Figure 4. Aerial view of experimental block, outlined in red, along I-86 near Highline Road in Chubbuck, ID.

Figure 5. Photo of pre-experiment vegetation along I-86 before constructing experimental plots.

The U.S. Highway 30 (US-30) site is at Milepost 362.4 near the junction of East Price Road near McCammon, Idaho (42°37’40.0116” N; 112°10’9.1704” W). The plots are located in the highway right-of-way north of the westbound lanes (Figure 6). The slope has an azimuth of 200° (southwest) on a 50% slope. This location is predominately covered in cheatgrass, with fewer weedy forbs, such as tumble mustard or kochia, compared to the I-86 site (Figure 7).

The species that were identified at the two highway sites before the experimental plots were constructed are listed in Table 4.

Figure 6. Aerial view of the experimental site, outlined in red, along US-30 near the junction of East Prince Road near McCammon, ID.

Figure 7. View of existing vegetation along US-30 before constructing experimental plots on US Highway 30 near McCammon, ID.

Table 4. List of plant species identified within the project's two highway roadside experimental sites along US Highway 30 and Interstate Highway 86 in ITD District 5 before site preparation.

Plant Group	List of Plants in Group
Grasses	Slender wheatgrass (*Elymus trachycaulus*), Canadian wild rye hybrid, Intermediate wheatgrass (*Thinopyrum intermedium*), Russian wildrye (*Psathyrostachus junceus*), Common wheat (*Triticum aestivum*)
Forbs, Shrubs, and Trees	Common yarrow (*Achillea millefolium*), Showy milkweed (*Asclepias speciosa*), Annual sunflower (*Heilanthus annuus*), Rubber rabbitbrush (*Ericameria nauseosa*), Big basin sagebrush (*Artemisia tridentata*), Willowherb (E*pilobium brachycarpum*), Boxelder maple (*Acer negundo*), Lamb's quarters (*Chenopodium album*), Beard's tongue (*Penstemon spp.*), Prostrate knotweed (*Polygonum aviculare*), Blanket flower (*Gaillardia aristata*)
Weedy Forbs	Kochia (*Kochia scoparia*), Tumble mustard (*Sisymbrium altissimum*), Musk thistle (*Carduus nutans*)*, Sweet wormwood (*Artemesia biennis*), Yellow salsify (*Tragpogon dubius*), Clasping pepperweed (*Lepidium perfoliatum*), Russian thistle (*Salsola tragus*), Bushy knotweed (*Polygonum ramosissimum*), Dyer's woad (*Isastis tinctoria*)*, Prickly lettuce (*Lactuca serriola*), Field bindweed (*Convolvus arvensis*)*, Curly dock (*Rumex cripus*), Shephard's purse (*Capsella bursa-pastoris*), Western tansymustard (*Descurainia pinnata*), Canadian thistle (*Cirsium arvense*)*, Dandelion (*Taraxacum officinale*)
Weedy Grasses	Downy brome (*Bromus tectorum*), Green bristle grass (*Setaria viridis*), Bulbous bluegrass (*Poa bulbosa*), Annual false wheatgrass (*Eremopyrum triticeum*)

* Noxious weed

3.2.3 Plot Construction

This experiment sought to simulate a post-construction re-vegetation and slope stabilization project. Thus, efforts were made to create similar conditions for vegetation establishment at the two experimental sites.

To prepare the sites for broadcast seeding and subsequent coverage by ECBs, the following process was followed:

- Demarcate the boundaries of the block design at each highway test site.
- Remove all surface vegetation in the block by mowing, weeding, and raking (Figure 8).
    - For the I-86 site, it was necessary to roto-till the soil to the depth of approximately 10 cm to prepare the site for broadcast seeding. Roto-tilling physically broke up dense clumps of roots and heavy thatch layer from two annual exotic species – cheatgrass and tumble mustard – that dominated the site (Figure 9).
- Collect soil samples to analyze the existing soil fertility at the two highway test sites.
- Mark the location of each of the randomized test plots with stakes.

Figure 8. The I-86 plot cleared of surface vegetation, prior to installing experimental plots.

Figure 9. Researcher roto-tilling the soil along I-86 after surface vegetation has been cleared.

A random block design with 10 replications of randomly located 1 m by 5 m plots covered by the various ECBs or left bare for the control plots was constructed at both experimental sites. One set of control plots (n=10) was not seeded (bare soil), another was seeded but did not receive any ECB. The third type of control plot was seeded and covered by the coir-straw ECB.

The I-86 experimental site had four types of woolen ECBs and three types of control treatments. Thus, seven overall types of treatments and 10 replications of each were randomly assigned for each 1 m by 5 m test plot (Figure 10).

I-86 Plot Map

Rep 1							Rep 2							Rep 3							Rep 4							Rep 5						
T1	T3	T4	T2	C3	C1	C2	C1	T2	C3	T4	T1	T3	C2	C1	T4	C3	T3	T1	C2	T2	C1	T1	T3	T4	T2	C3	C2	T3	C2	C1	C3	T2	T4	T1

Rep 6							Rep 7							Rep 8							Rep 9							Rep 10						
C1	C3	T3	T1	C2	T2	T4	T3	T2	C3	T1	C1	C2	T4	C3	C2	T2	T4	T3	C1	T1	C2	T4	T2	C3	C1	T1	T3	T3	T2	T1	C2	C1	T4	C3

Controls

C1 = Bare Soil

C2 = Broadcast Seed Only

C3 = Coconut Coir Blanket and Broadcast

Tests

T1 = 100% Wool and Broadcast

T2 = 70% Wool 30% Straw and Broadcast

T3 = 50% Wool 50% Straw and Broadcast

T4 = 30% Wool 70% Straw and Broadcast

Figure 10. The I-86 block map of the repetitions and the randomization of the seven different plot treatments.

Prior to the installation of each ECB, each 1 m by 5 m test plot received an equal amount of the seed mix that was broadcast by hand. The amount of seed mix was 6.95 g/m^2 per square meter (Table 3) or 34.75 g per experimental plot. After the plots were seeded, they were covered by various replications of the different ECBs. Two of the three control treatments also received the same seed mix at the same rate as the ECB experimental plots – the bare soil experimental plots and the experimental plots covered by coir-straw ECBs.

Each experimental plot was placed side by side and the edges were covered with soil to prevent potentially damaging wind from getting under the ECB and ripping it off the test plot or tearing the fabric. Each ECB was also secured with sod staples around its perimeter (Figure 11). The original width of each ECB was 1.2 m wide (4 feet), so it allowed 10 cm of each edge to be covered with soil so that 1 m wide swaths of ECB were still effectively uncovered by soil. Similarly, extra length at the top and bottom of each ECB allowed each blanket to be attached to the soil with sod staples and covered by soil so that 5 m of effective length remained. After the 70 plots were laid out and constructed on 3 November 2018 (Figure 12), they were left untouched until vegetative measurements were collected in each of three successive years on the last week of June or first week of July.

Figure 11. Researchers installing ECB blankets with sod staples. The ECB was placed over a plot that was broadcast seeded at the I-86 highway roadside test site.

Figure 12. ECBs and bare control experimental plots after all the treatment repetitions have been installed along I-86.

The US-30 experimental block was laid out based on the experimental design as described for the I-86 test block. However, there are three key differences in the US-30 and the I-86 experimental blocks. First, the US-30 site is on a curve, while the I-86 site is on a straight road segment. To ensure that the aspect of the slope did not change across the test block, the test plots were placed in two rows along the slope to maintain a consistent azimuth or aspect for the experiment (Figure 13).

Figure 13. ECB after all the repetitions have been installed along US-30.

Second, the US-30 experimental site was too steep to roto-till. Lastly, there were no 100% wool ECB experimental plots established for the US-30 test block. There was not enough 100% wool ECB to cover both test blocks. Thus, for the US-30 test block, there were three wool-straw ECBs of different ratios randomly distributed in each experimental plot (Figure 14).

All 60 test plots were constructed on 2 November 2018 at the US-30 test block. There were 10 replications of the three types of wool-straw ECBs and the three types of control plots. They were left untouched until vegetative measurements were collected in each of three successive years.

US Hwy 30 Plot Map

Rep 1						Rep 2						Rep 3						Rep 4						Rep 5					
T4	T3	T2	C3	C1	C2	C1	T2	C3	T4	T3	C2	C1	C3	T3	T4	C2	T2	C1	T4	T3	T2	C3	C2	T3	C2	C1	C3	T2	T4

Rep 6						Rep 7						Rep 8						Rep 9						Rep 10					
C1	C3	T3	T4	C2	T2	T3	T2	C3	T4	C1	C2	C3	C2	T2	T3	C1	T4	C2	T2	C3	C1	T4	T3	T3	T2	T4	C2	C1	C3

<u>Controls</u>

C1 = Bare Soil

C2 = Broadcast Seed Only

C3 = Coconut Coir Blanket and Broadcast

<u>Tests</u>

T2 = 70% Wool 30% Straw and Broadcast

T3 = 50% Wool 50% Straw and Broadcast

T4 = 30% Wool 70% Straw and Broadcast*

*Changed from T1 to match I-86

Figure 14. US-30 block map of the repetitions and the randomization of the plot treatments.

Figure 15. Block along US-30 in February 2019, showing the ECB were protected by snow from strong winds during the 2018-2019 winter season.

3.3 Data Collection

After plot construction was finished in fall 2018, vegetative measurements were collected late in each of the three successive growing seasons. All vegetative data collection occurred in the last week of June or first week of July in 2019, 2020, and 2021. The success of vegetation establishment and growth was measured by a species' percent plant canopy cover. Canopy cover is the vertical projection of the crown or shoot area of a species projected on the ground as a percent of the reference area. Since canopy cover approximates above ground biomass (e.g., Ludwig et al. 1975, Jin et al. 2014), canopy cover is considered a good indicator of a species' control over, or consumption of, resources such as water and nutrients at the site.

3.3.1 Vegetation – Small Quadrats

The percent vegetative canopy cover of each species was measured within the boundaries of a 20 cm by 50 cm rectangular PVC pipe frame ('quadrat'), which is equivalent to 0.1 m^2. Five quadrats were randomly located in each experimental plot. The location of the sampling quadrat was predetermined for each year by randomly picking numbers that represented unsampled quadrat locations. This ensured there was no duplication of area measurements within each treatment and therefore no sampling bias was applied to the location of the quadrats within each experimental plot. As a result, each year of the data is independent of the previous year's data.

The quadrats were set along either side of a center line running the length of the experimental plot at the time of data collection and then removed upon completion of each recording. An example of the sampling process for each experimental plot with different treatments can be seen in Table 5. For small quadrat sampling, canopy cover for each species was estimated with integer percentages 1-15%, and then sequentially in increments of 5% between 15% and 100% (e.g., 15%, 20%, 25%…95%, 100%). This sampling method was conducted for all three years of data collection.

Table 5. Example of randomization of sampling quadrats (50 cm x 20 cm) to measure vegetative canopy cover in each experimental plot (1 m x 5 m).

T 1	T 1	T 2	T2	T 3	T 3	T 4	T 4	T 5	T 5	T 6	T 6
50	49	50	49	50	49	50	49	50	49	50	49
48	47	48	47	48	47	48	47	48	47	48	47
46	45	46	45	46	45	46	45	46	45	46	45
44	43	44	43	44	43	44	43	44	43	44	43
42	41	42	41	42	41	42	41	42	41	42	41
40	39	40	39	40	39	40	39	40	39	40	39
38	37	38	37	38	37	38	37	38	37	38	37
36	35	36	35	36	35	36	35	36	35	36	35
34	33	34	33	34	33	34	33	34	33	34	33
32	31	32	31	32	31	32	31	32	31	32	31
30	29	30	29	30	29	30	29	30	29	30	29
28	27	28	27	28	27	28	27	28	27	28	27
26	25	26	25	26	25	26	25	26	25	26	25
24	23	24	23	24	23	24	23	24	23	24	23
22	21	22	21	22	21	22	21	22	21	22	21
20	19	20	19	20	19	20	19	20	19	20	19
18	17	18	17	18	17	18	17	18	17	18	17
16	15	16	15	16	15	16	15	16	15	16	15
14	13	14	13	14	13	14	13	14	13	14	13
12	11	12	11	12	11	12	11	12	11	12	11
10	9	10	9	10	9	10	9	10	9	10	9
8	7	8	7	8	7	8	7	8	7	8	7
6	5	6	5	6	5	6	5	6	5	6	5
4	3	4	3	4	3	4	3	4	3	4	3
2	1	2	1	2	1	2	1	2	1	2	1

Table 5 Abbreviation: T = treatment

3.3.2 Vegetation - Large Quadrats (2021)

Vegetative canopy cover data from growing season one (2019) and growing season two (2020) were analyzed to determine if the mean vegetative canopy cover of seed mix species or weedy species were higher or lower among and between the different ECB types and the control plots after each season. Although there were differences in the mean percent canopy cover of seeded species and weedy species between treatments in each growing season, there was little statistical evidence that the differences were significant. After conferring with several statisticians, the WTI research team hypothesized that the small quadrats might create high variability, and thus 10 replications might be insufficient to capture the patchiness of the small native perennial grasses that were established from the seed mix. Thus, a larger sample quadrat size might lead to less variability and the opportunity to determine if the mean differences in canopy cover between the different treatments were statistically significant.

For growing season three (2021), a ‘large’ sampling quadrat method was also used (1 m^2). In addition to measuring five random small quadrats for each experimental plot consistent with Year 1 and Year 2, vegetative canopy cover was also measured using two large quadrats randomly located in each experimental plot.

Unlike the small sample quadrats where percent canopy cover for each species was estimated to integer percentages from 1-15%, and then by five percentage points from 15-100%, the measurements for each large sample quadrat was measured by cover class (e.g., 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%) (Daubenmire 1959). The mid-point of each of these groups is recorded as the measured data.

T-tests were conducted separately on the results of the large and small quadrat data to determine if differences between the vegetative groups mean canopy cover were statistically meaningful between treatments. The larger quadrats statistical test results were then compared to the smaller quadrats statistical test results to determine if there were any differences in their ability to achieve statistical significance for the differences in mean vegetative canopy cover under the different treatments.

3.3.3 Erosion

Each experimental site’s topsoil was smoothed with a rake in preparation for the broadcast seeding. None of the prepared experimental plots exhibited erosion at the start of the experiment. At the I-86 experimental site, an existing erosion rill was avoided (excluded from) experimental plot construction (Figure 16). Erosion measurements were taken after completion of the experiment in Year 3, because at that time the ECBs had decomposed and the underlying soils and plants were exposed.

Erosion was qualitatively evaluated using the Bureau of Land Management’s “Erosion Condition Class Determination” method (Clark 1980), which uses a numeric scoring system to estimate the frequency and distribution of rills, gullies, surface soil movement, soil pedestals, litter movement, and presence of surface flow patterns. The scoring categorizes the experimental site’s test plots into an erosion condition class (stable, slight, moderate, critical, and severe).

Figure 16. I-86 experimental site in July 2020 after the second year of plant growth, looking west. Red circle is location of erosion caused by unmitigated surface runoff where plot construction was avoided.

3.3.4 Soil Sampling

Initial tests of soil properties were conducted to examine the fertility of each roadside highway test site before conducting the research experiment. Bulk samples of soils were collected on 28 September 2018 from each site in a one-gallon plastic bag. A small soil pit of 25 cm (10 inches) deep was hand dug with a trowel at 10 random locations at each highway test site. Then a thin layer of soil from the top to the bottom of pit was removed and placed in the bag. The 10 samples were combined as a bulk sample for analysis of various soil characteristics and chemical parameters at Energy Laboratories, Inc. in Billings, Montana.

At the conclusion of vegetative sampling on 1 July 2021, additional bulk soil samples were collected at each experimental site. To provide the best opportunity to detect increases in soil nitrogen under woolen ECBs, the WTI research team selected the woolen ECB replicates with the highest component of wool at each experimental site to collect bulk soil samples.

For the US-30 experimental site, a bulk sample was collected for the control plots that received neither seeding nor an ECB, as well as for the ECB plots under the 70% wool-30% straw ECBs. For I-86, a bulk sample was collected for the control plots that received neither seeding nor an ECB, as well as for the ECB plots under the 100% wool ECBs.

3.3.5 Vegetative Canopy Cover

The percent canopy cover of each species was measured in each quadrat. After data collection, each of the forbs and grasses were placed in one of the following vegetative groups:

1. Species in the seed mix
2. Other grasses
3. Other forbs, shrubs, and trees
4. Weedy grasses (dominated by cheatgrass)
5. Weedy forbs

In addition, noxious weeds were identified in the species list, but their mean canopy cover was not significant in any of the experimental plots, so noxious weeds were not analyzed as a separate vegetative group. A list of all the species identified in the sampling quadrats, and into which of the vegetative groups they were placed, is provided in Table 6.

Table 6. List of species identified in sampling quadrats at the two experimental sites and the vegetative group to which they were placed.

Plant Group	Species	Found along US-30	Found along I-86
Seed Mix	Canby bluegrass (*Poa secunda*)		Yes
Seed Mix	Bottlebrush squirreltail (*Elymus elymoides*)	Yes	Yes
Seed Mix	Bluebunch wheatgrass (*Pseudoroegneria spicata*)	Yes	Yes
Seed Mix	Thickspike wheatgrass (*Elymus lanceolatus*)	Yes	Yes
Seed Mix	Western wheatgrass (*Pascopyrum smithii*)	Yes	Yes
Other Grass	Slender wheatgrass (*Elymus trachycaulus*)		Yes
Other Grass	Russian wildrye (*Psathyrostachus junceus*)		Yes
Other Grass	Canadian wild rye hybrid	Yes	Yes
Other Grass	Intermediate wheatgrass (*Thinopyrum intermedium*)		Yes
Other Grass	Common wheat (*Triticum aestivum*)		Yes
Other Forbs, Shrubs, and Trees	Showy milkweed (*Asclepias speciosa*)	Yes	Yes
Other Forbs, Shrubs, and Trees	Annual sunflower (*Heilanthus annuus*)	Yes	Yes
Other Forbs, Shrubs, and Trees	Rubber rabbitbrush (*Ericameria nauseosa*)		Yes
Other Forbs, Shrubs, and Trees	Big basin sagebrush (*Artemisia tridentata*)		Yes
Other Forbs, Shrubs, and Trees	Willowherb (*epilobium brachycarpum*)		Yes
Other Forbs, Shrubs, and Trees	Boxelder maple (*Acer negundo*)		Yes
Other Forbs, Shrubs, and Trees	Common yarrow (*Achillea millefolium*)	Yes	Yes
Other Forbs, Shrubs, and Trees	Beard's tongue (*Penstemon spp.*)		Yes
Other Forbs, Shrubs, and Trees	Prostrate knotweed (*Polygonum aviculare*)	Yes	Yes
Other Forbs, Shrubs, and Trees	Blanket flower (*Gaillardia aristata*)	Yes	Yes
Other Forbs, Shrubs, and Trees	Lamb's quarters (*Chenopodium album*)	Yes	Yes
Weedy Grass	Downy brome (*Bromus tectorum*)	Yes	Yes
Weedy Grass	Bulbous bluegrass (*Poa bulbosa*)		Yes
Weedy Grass	Green bristle grass (*Setaria viridis*)		Yes
Weedy Grass	Annual false wheatgrass (*Eremopyrum triticeum*)		Yes
Weedy Forbes	Kochia (*Kochia scoparia*)	Yes	Yes
Weedy Forbes	Tumble mustard (*Sisymbrium altissimum*)	Yes	Yes
Weedy Forbes	Musk thistle (*Carduus nutans*)*	Yes	Yes
Weedy Forbes	Western tansymustard (*Descurainia pinnata*)	Yes	Yes
Weedy Forbes	Sweet wormwood (*Artemesia biennis*)		Yes
Weedy Forbes	Yellow salsify (*Tragpogon dubius*)	Yes	Yes
Weedy Forbes	Clasping pepperweed (*Lepidium perfoliatum*)	Yes	Yes
Weedy Forbes	Russian thistle (*Salsola tragus*)		Yes
Weedy Forbes	Bushy knotweed (*Polygonum ramosissimum*)	Yes	Yes
Weedy Forbes	Dyer's woad (*Isastis tinctoria*)*	Yes	Yes
Weedy Forbes	Prickly lettuce (*Lactuca serriola*)	Yes	Yes
Weedy Forbes	Field bindweed (*Convolvus arvensis*)*	Yes	Yes
Weedy Forbes	Curly dock (*Rumex cripus*)		Yes
Weedy Forbes	Shephard's purse (*Brassicaceae Capsella*)	Yes	Yes
Weedy Forbes	Canadian thistle (*Cirsium arvense*)*	Yes	Yes
Weedy Forbes	Dandelion (*Taraxacum officinale*)	Yes	Yes

3.4 Statistical Analysis

The single variable to measure the success of a plant species' establishment, growth, and relative control of resources in each quadrat was its canopy cover. A calculation of the mean percent canopy cover for each species and then in turn for each vegetative group was calculated for each experimental plot. The mean canopy cover, for each vegetative group, for each treatment, was the summation of the ten replications (n=10) at each experimental site. These means of percent canopy cover were used in the statistical analyses.

The mean percent canopy cover for each of the five vegetative groups were compared using an analysis of variance (ANOVA) conducted in R 3.5.1 (R CoreTeam, 2020), to identify if the differences of the mean percent canopy cover between the vegetative groups for each treatment were statistically significant. Each of the treatments (Table 1) at both experimental sites were then compared to each other using the Tukey honest significant difference (HSD) function (R Core Team, 2020). This process compares each of the different combinations of vegetative groups by treatment using a pair-wise t-test and reports the probability of obtaining the observed results (p-values) for each comparison. It also creates confidence intervals on the differences between the means of the treatments with the specified family-wise probability of coverage. The intervals are based on the studentized range statistic which estimates the population group variance from the collected sample. This is used to determine if the groups do or do not have the same variance based on each group sample, making the statistical tests more accurate.

4. Results

4.1 Soil Properties

The soil properties and fertility levels from the two experimental sites' (US-30 and I-86) bulk soil samples reveal differences in various nutrient levels and physical characteristics. The pre-experimental results were returned from Energy Laboratories, Billings, MT, in October 2018. The post-experiment results were received from Energy Laboratories in August 2021. Lab results are from bare soil samples collected before plot construction in 2018 and from samples collected at the conclusion of the experiment within the control plots which were not seeded and did not receive any ECBs in 2021. In addition, bulk soil samples were collected at the conclusion of the experiment from the highest woolen ECB replicate at each highway test site – %100 wool ECBs at I-86 and the 70% wool-30% straw ECBs at the US-30 experimental site.

Pre-experiment values
The three macronutrients – nitrogen, phosphorous, and potassium – were measured in the soil samples and their levels at each experimental site; the results are reported in Table 7. These three nutrients are called macronutrients, since larger amounts of these three nutrients are necessary for plant growth and health compared to other nutrients such as sulfur, magnesium, or manganese (micronutrients).

Nitrate (NO_3^-) is the form of nitrogen that can be absorbed by plants for growth. Levels of nitrate in the soil were nearly four times higher on the I-86 site (27 mg/kg) compared to the US-30 site (7 mg/kg) before the experiment was started, although total Kjeldahl nitrogen (total of ammonia-nitrogen and organically bound nitrogen) concentrations are similar at both sites (Table 7). Nitrate availability at these levels leads to various recommendations for adding nitrogen fertilizer, depending on organic matter (OM) levels of the soil (Moore et al. 2011). Recommendations from Moore and others (2011) are for Idaho homeowner crops and lawns. It should be noted for native plant communities soil fertility level recommendations are not nearly as high as those for the cultivation of crops and produce, or homeowner shrubs, trees, and grasses in lawns.

Phosphorus levels were well over twice as high at the I-86 site (88 mg/kg) than at the US-30 site (33 mg/kg) (Table 7). The University of Idaho Extension Office does not recommend any phosphorous fertilizer if the Olsen test for phosphorous indicates concentrations greater than 30 mg/kg for horticultural species (Moore et al. 2011). There were adequate phosphorous levels in the soil at both experimental sites since native plant communities would require even lower levels than for horticultural crops.

Potassium levels were similar at the I-86 (651 mg/kg) as at the US-30 site (738 mg/kg) (Table 7). Fertilizing soils with potassium levels greater than 500 mg/kg is adequate for horticultural crops in Idaho (Moore et al. 2011); thus, they were also adequate for native plant communities.

The Soil Adsorption Ratio (SAR) value is a measure of sodium in the soil. Excessive sodium in a soil can result in detrimental effects to plant growth and water retention. If SAR values exceed 13 the soils are considered problematic. Both roadside test sites had SAR values of 12 or lower (Table 7).

Table 7. Soil characteristics and fertility results for the 2 experimental sites, before and after the experiment – US Highway 30 (US-30) and Interstate Highway 86 (I-86) in Idaho Transportation Department's District 5 of Idaho.

Analytical Test[1]	US-30 Bulk Soil Sample (2018)	US-30 Bare Soil Plot (2021)	US-30 70% Wool and 30% Straw Plot (2021)	I-86 Bulk Soil Sample (2018)	I-86 Bare Soil Plot (2021)	I-86 100% Wool Plot (2021)
pH s.u.	7.4	7.5	7.5	7.7	7.4	7.3
Saturation %	54.1	45.3	42.5	35.8	33	34.5
Electric Conductivity (EC) dS/m	1	1.4	1	2.3	11	13.1
Sodium Adsorption Ratio	0.8	1.97	2.14	3.1	7.73	12
Calcium (Ca) mg/L	130	174.1	113.8	178	1881.8	2324.6
Magnesium (Mg) mg/L	23	22.2	15.8	38	312.3	383.9
Sodium (Na) mg/L	40	103.9	91.7	174	1374.8	2368
Organic Matter %	7	4.7	4.4	3.2	2.6	2.9
Organic Carbon %	4.1	2.7	2.5	1.9	1.5	1.7
Carbon Nitrogen Ratio	18.4	12.4	12.5	8.9	8.3	8.7
Potassium (K) mg/kg	738	685	739	651	939	898
Phosphorus (P) mg/kg	33	45	39	88	60	54
Nitrate (NO_3) mg/kg	7	8	8	27	188	174
Kjeldahl Nitrogen (N) mg/kg	2200	2200	2020	2080	1620	1770

[1] Units: s.u. = saturated units; % = percent; dS/m=deciSiemens per meter; mg/L = milligrams per liter; mg/kg = milligrams per kilogram

The two sites have OM levels of 3.2% (I-86) and 7% (US-30), that also contribute nitrogen for plant growth as it decomposes (Table 7). Soil OM is the fraction of the soil that consists of plant or animal tissue in various stages of decomposition. It is common for productive agricultural soils to have between 3 and 6% organic matter (Cornell University 2008). Thus, OM levels are adequate at each experimental site.

Post-experiment values

The slow decomposition of the wool in the various wool-straw ECB treatments provided nitrate for plant growth during the length of the experiment. At the end of the experiment, in July 2021, there still were some small clumps of wool observed in the ECBs, with the 100% wool ECB having the most noticeable amount of wool yet to decompose. It was highly likely the slow release of nitrogen from the wool over time was beneficial for plant growth and resulted in higher canopy cover.

At the US-30 site, total Kjeldahl nitrogen and nitrate levels in the soil did not noticeably change after conducting the experiment, either in the control plots or in the 70% wool-30% straw ECB plots.

Conversely, at the I-86 site, total nitrogen was relatively the same before and after the experiment in the control plots, while the 100% wool ECBs had a lower value for total Kjeldahl nitrogen than either control. The lower level of nitrogen under a 100% wool ECB compared to the control plots was unexpected. Since each treatment had only one bulk sample, there could be no determination of the variability of the results, which might explain such low total nitrogen values for soils under the 100% wool ECB. This is also reflected in the nitrate levels in the bulk samples for I-86, where they increased significantly after three growing seasons under the 100% wool ECB and the control. Again, a determination for the cause of a six-fold increase in nitrate levels in untreated soil is difficult to make, other than a high variability among the bulk samples.

4.2 Erosion

At the I-86 experimental site, there was no evidence of erosion in any of the experimental plots. Vegetative canopy cover completely protected the site, although most of the cover was provided by weedy species by the end of the first growing season in 2019 (Figure 17).

Figure 17. I-86 test site in July 2019 after the first year of plant growth, looking west.

Similarly, visual analysis of the experimental site’s plots along US-30 indicated that vegetation was dense, although weedy, by the end of the first growing season. Thus, no erosion occurred either in the bare soil control plots or in the ones that were covered by the various types of ECBs (Figure 18)

Figure 18. Experimental test site along US-30 in the first week of July 2019.

4.3 Vegetation Canopy Cover Measurements and Analysis

4.3.1 Introduction

The roadside establishment of seeded native perennial plants can take several years after disturbance by highway construction activities to establish themselves in adequate amounts. The amount of canopy cover that is targeted for restoration can vary by site and native plant community and is usually defined in highway revegetation contracts. Some species seeds require cold stratification – extended time at temperatures below 40 degrees Fahrenheit (4 degrees Celsius) and exposure to moisture – both factors vary by species, to aid germination. Other species may require shade or other environmental factors that may influence their rate of establishment. After disturbance, soil microbial activity also takes time to recover, this activity is an important factor in plant germination and growth. In general, seeded plant species canopy cover is expected to be quite low after the first growing season, although not for all species, seed mixes and environments.

It is not beyond expectation for the first year of vegetative canopy cover data to show little evidence for differences in plant establishment and growth of the seeded species based on the different ECB treatments and control plots. By the second year, more canopy cover may be anticipated as seedlings of the five seeded species establish and grow. It is anticipated by the third year, even further growth and establishment will result in increased canopy cover by the seeded species.

A significant drought encompassed the western United States in 2021, the third growing season for the project. The two experimental sites experienced unusually dry weather. Normal monthly precipitation averages nearly 1.25 inches (31.75 mm) in April, 1.5 inches (38.1 mm) in May, and nearly one inch (25.4 mm) in the month of June (Figure 19) at the nearby US climate data station for Pocatello, ID. (www.usclimatedata.com/climate/pocatello/idaho/united-states/usid0204). On average, the total mean precipitation for the three months before vegetation was measured approaches four inches (101.6 mm). Total precipitation for those three months was over four inches (101.6 mm) for the first growing season (2019) and the second growing season (2020) (Table 8).

Pocatello Climate Graph - Idaho Climate Chart

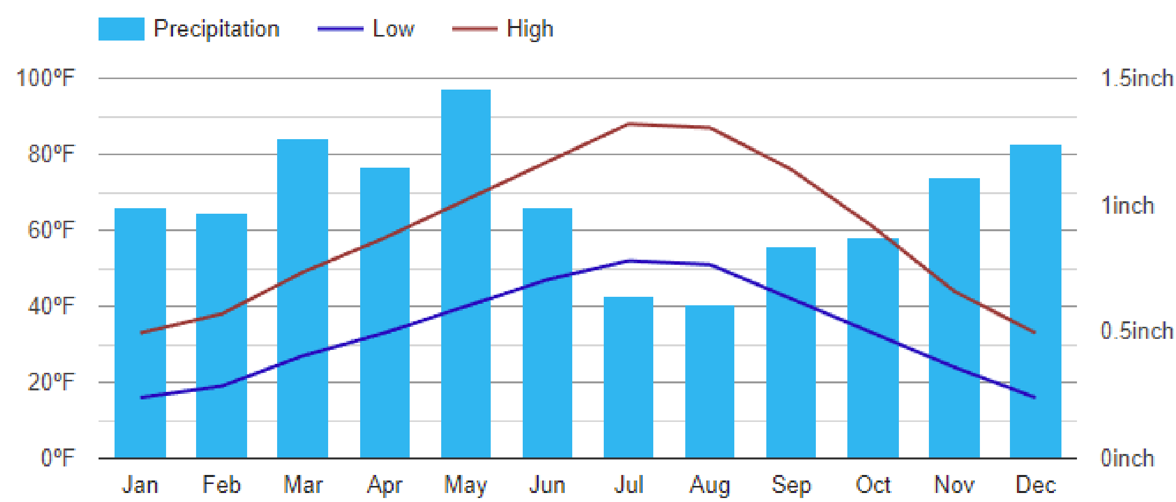


Figure 19. US climate data for Pocatello, ID. Mean monthly precipitation (light blue bars) shows low precipitation in summer months. Mean monthly low temperatures (dark blue line) and mean monthly high temperatures (red line) are elevated in the summer months. (www.usclimatedata.com/climate/pocatello/idaho/united-states/usid0204)

However, only 1.75 inches of precipitation was recorded in 2021 (Table 8), and only 0.01 inch (0.025 mm) the entire month of June, before the third growing season's canopy cover was measured. This resulted in the death of many of the young perennial grass seedlings that established from the seed mix in the first two years at both experimental sites.

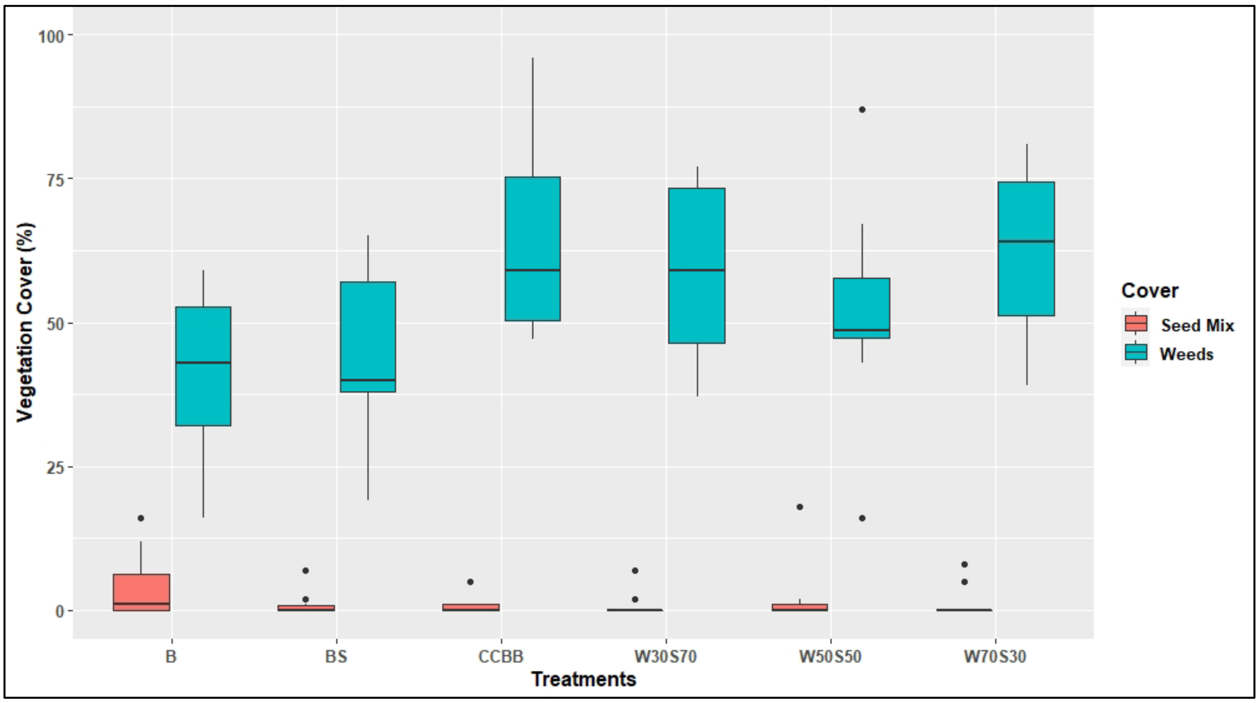
Table 8. Total precipitation at Pocatello, ID's national weather station for the three months of the growing season before vegetation was measured for the project.

Months	Year	Total Precipitation (inches)	Total Precipitation (mm)
April - June	2019	4.05	102.87
April - June	2020	4.41	112.01
April - June	2021	1.75	44.45

4.3.2 Vegetation Results in 2019

4.3.2.1 US-30 Experimental Site

The US-30 experimental site is dominated by weedy grasses, primarily cheatgrass and has much less weedy forb mean percent canopy cover compared to the I-86 experimental site (Figure 20). There is a higher mean percent canopy cover for the seed mix species than at the I-86 experimental site, but it is less than two percent for any of the treatments (Figure 20). There is no statistical evidence that the mean canopy cover of the seeded or weedy species' is significantly different between the ECB treatments. There was no wool ECB treatment that significantly outperformed any of the others in the first year.

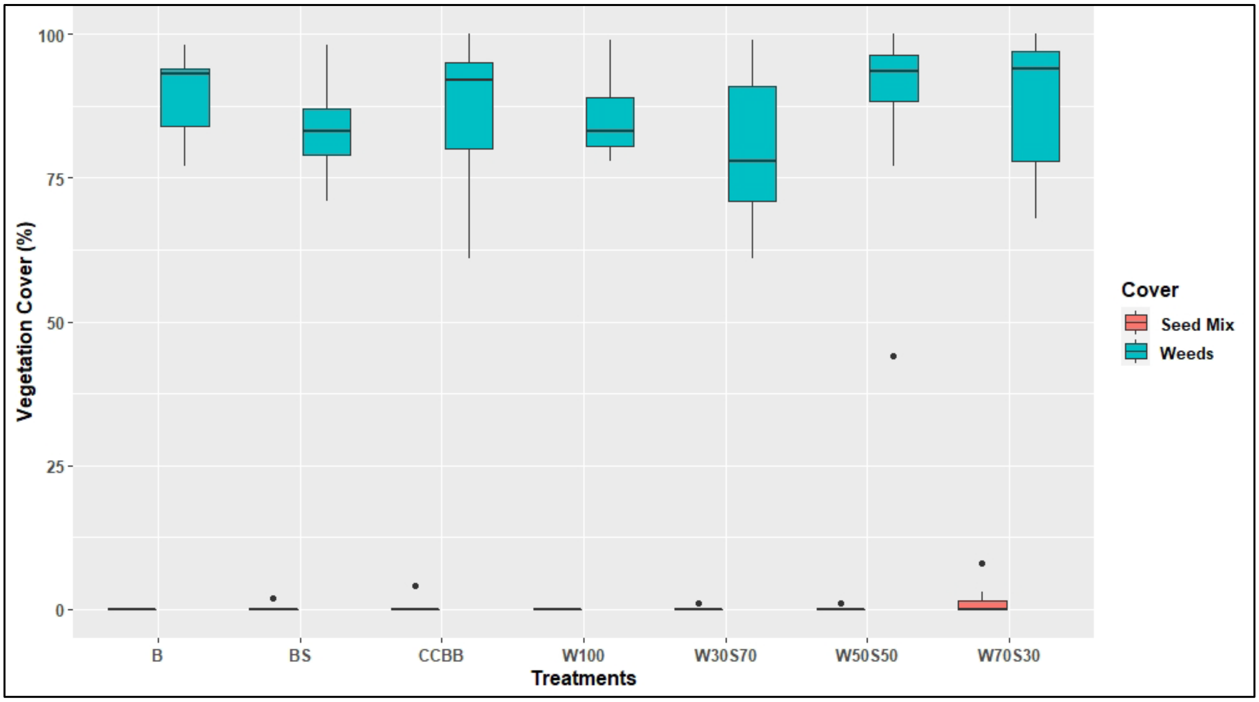


Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W70S30 = 70% wool to 30% straw ECB over broadcast seed mix; W50S50 = 50% wool to 50% straw ECB over broadcast seed mix; W30S70 = 30% wool to 70% straw ECB over broadcast seed mix.

Figure 20. Mean vegetative canopy cover of seed mix (pink boxes) and weedy species (blue boxes) at US-30 experimental site in 2019. Weedy species comprise a greater percentage of vegetation cover than seed mix species.

4.3.2.2 I-86 Experimental Site

The seed mix species mean percent canopy cover was very low for all treatments; all had means that were less than one percent across all types of ECBs and the control plots at the I-86 experimental site (Figure 21). There are no treatment comparisons that show any statistical evidence that there are differences between the treatments (p-value ≤ 0.05). The 70% wool-30% straw ECB had the highest mean canopy cover for seeded species of all the treatments. Weedy species mean canopy cover exceeded 75% for all of the control and ECB treatments, indicating the various weed species quickly re-established themselves in the first growing season (Figure 21).



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool - 50% straw ECB over broadcast seed mix; W30S70 = 30% wool - 70% straw ECB over broadcast seed mix.

Figure 21. Mean vegetative canopy cover of seed mix (pink boxes) and weedy species (blue boxes) at I-86 experimental site in 2019. Weedy species comprise a greater percentage of vegetation cover than seed mix species.

4.3.2.3 2019 Summary of Vegetation Results

1. The seed mix species had very low levels of establishment under any of the ECBs. They had a mean percent canopy cover of less than two percent across all ECB treatments at both highway experimental sites.
2. Both highway experimental sites were dominated by weedy species after the first year.

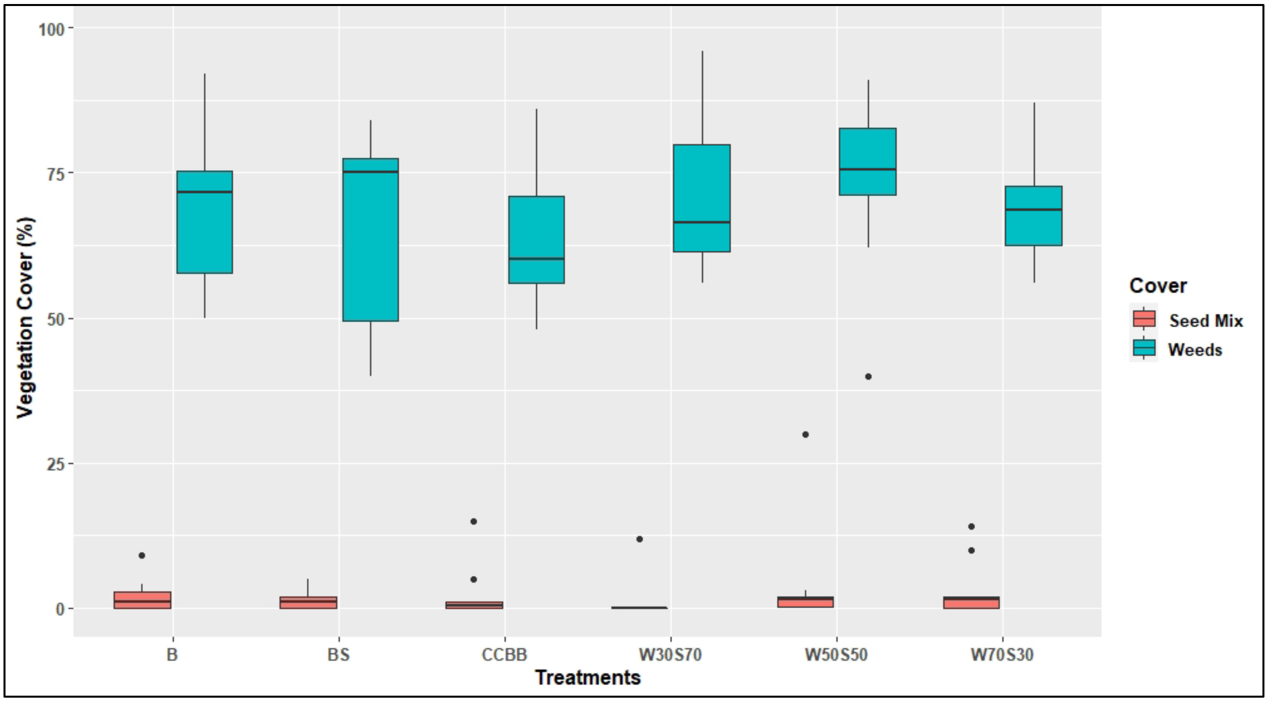
3. There were two noticeable differences between the sites: in general, there were more weedy forbs at I-86 across all treatments, and more weedy grasses, primarily cheatgrass, at US-30 across all treatments.
4. Any differences in the mean percent canopy cover of the vegetative groups, by treatment, were not statistically significant.

4.3.3 Vegetation Results in 2020

Overall, in 2020, the seed mix species mean percent canopy cover was 2% or lower under the various wool ECBs. It was unclear after two growing seasons, whether the dominance of weedy species at both sites precluded the establishment and growth of seeded native perennial grasses. A comparison of the seed mix species and the weedy vegetative groups' mean percent canopy cover, at each experimental site, by treatment, indicated there were few statistically significant differences, but there are some notable findings discussed below.

4.3.3.1 US-30 Experimental Site

The seed mix species mean percent canopy cover of 3.02% was the highest in the 70% wool-30% straw ECB, when compared to all other treatments at the US-30 experimental site (Figure 22). Total weedy species mean percent canopy cover was high (62.9-73.8%) across all types of ECBs and the control treatments. Based on p-values from the statistical analyses, there were no statistically significant differences (p-value < 0.05) for the total mean percent canopy cover of seed mix or weedy species between the different ECB treatment types and the control treatment types.



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W70S30 = 70% wool to 30% straw ECB over broadcast seed mix; W50S50 = 50% wool to 50% straw ECB over broadcast seed mix; W30S70 = 30% wool to 70% straw ECB over broadcast seed mix.

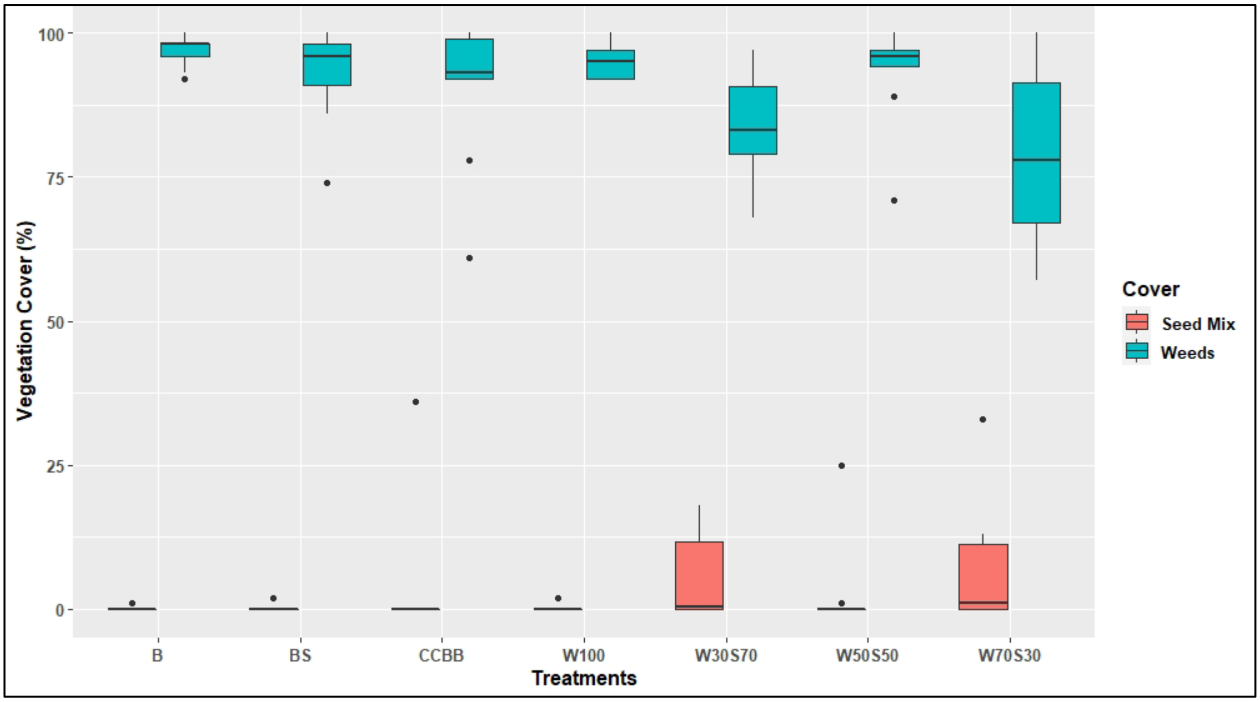
Figure 22. Mean vegetative canopy cover of seed mix (pink boxes) and weedy species (blue boxes) at US-30 experimental site in 2020. Weedy species comprise a greater percentage of vegetation cover than seed mix species.

4.3.3.2 I-86 Experimental Site

In general, the I-86 experimental site's treatments had slightly higher mean percent canopy cover for seed mix species when compared to US-30 (2.7% compared to 2.4%). Both sites still have a large proportion of weedy grass species, primarily cheatgrass, but the US-30 location had a slightly higher mean canopy cover (48% compared to 43%). Mean canopy cover of the weedy grass and weedy forb species, combined, was almost 68% at the US-30 site, which was lower than nearly 81% at the I-86 site.

At the I-86 experimental site, the experimental plots covered by the 70% wool-30% straw ECB had the greatest mean percent canopy cover (6.9%) for the seed mix species compared to all other treatment types (Figure 23). However, there is no statistically significant difference between the different ECB types and the control treatments for the mean percent canopy cover of the seed mix species after the second year of growth in 2020.

The mean canopy cover of the weedy species at I-86 was high for all treatments, varying between 82-97% (Figure 23). The only statistically significant difference (p-value = 0.034) was for the mean percent canopy cover of weedy species between the 70% wool-30% straw ECB and the bare soil without seed in the control treatment. It should be noted that all the p-values for the pair-wise t-tests for all the treatments and at both experimental sites are not displayed, since so few had values of 0.05 or lower.



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool - 50% straw ECB over broadcast seed mix; W30S70 = 30% wool - 70% straw ECB over broadcast seed mix.

Figure 23. Mean vegetative canopy cover of seed mix (pink boxes) and weedy species (blue boxes) at I-86 experimental site in 2020. Weedy species comprise a greater percentage of vegetation cover than seed mix species.

4.3.3.3 2019-2020 Mean Canopy Cover Comparisons

There were statistically significant differences in the seed mix species mean percent canopy cover when comparing results from Year 1 (2019) to Year 2 (2020). A one-sided t-test was conducted to identify if any of the annual increases in mean percent canopy cover for the seed mix vegetative group were significant for any of the treatments, from 2019 to 2020.

Table 9 presents results that indicate all the ECB treatments had an increase in seed mix species mean canopy cover from the initial year to the second year at the I-86 experimental site. All three control treatments also had increases in seed mix species mean canopy cover, but none were statistically significant.

Of the four different wool ECB treatments, seed mix species mean percent canopy cover increased between 407% and 2,083% from year to year (Table 9). Two of the four wool ECB types' increases at the I-86 experimental site were statistically significant with p-values of 0.024 and 0.011 (Table 9).

At the US-30 experimental site, all three wool ECB treatments had increases in seed mix species mean percent canopy cover, but at lower levels compared to the I-86 experimental site, 47%-125 % (Table 9). The bare soil that was seeded and the coir-straw ECB that was also seeded had increases in seed mix species mean canopy cover. The increases in seed mix canopy cover between years was not statistically significant for any treatment (Table 9).

Table 9. Comparison of the mean percent canopy cover of seed mix species between 2019 and 2020 at both experimental sites.

Site	Treatment	2019 Mean (%)	2020 Mean (%)	t	df	p-value	% Change
I-86	B	0.02	0.26	-1.64	51	0.054	1200
I-86	BS	0.2	0.32	-0.63	91	0.265	60
I-86	CCBB	0.4	3.64	-1.52	50	0.067	810
I-86	W100	0.04	0.26	-1.15	53	0.128	550
I-86	W30S70	0.24	5.1	-2.03	49	0.024	2025
I-86	W50S50	0.12	2.62	-1.47	49	0.074	2083
I-86	W70S30	1.36	6.9	-2.36	56	0.011	407
US-30	B	4.06	2	1.08	73	0.857	-51
US-30	BS	1.04	1.48	-0.61	98	0.272	42
US-30	CCBB	0.8	2.36	-1.19	61	0.119	195
US-30	W30S70	0.86	1.26	-0.30	69	0.382	47
US-30	W50S50	2.18	4	-0.88	84	0.192	83
US-30	W70S30	1.34	3.02	-1.01	81	0.157	125

Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool-50% straw ECB over broadcast seed mix; W30S70 = 30% wool-70% straw ECB over broadcast seed mix; t = t-score from statistical test; df = degrees of freedom.

A summary of the changes in mean percent canopy cover of the weedy species vegetative group between Year 1 and Year 2 are displayed in Table 10. A one-side statistical t-test was conducted to identify if any of the increases or decreases in the weedy species vegetative group's mean canopy cover in the second year were statistically significant.

Most of the treatments experienced an increase in weedy species canopy cover (green), with no statistical evidence that the differences of the means were significant (p-value < 0.05). The only statistical evidence that the mean percent canopy cover of weedy species decreased from 2019 to 2020 (p-value = 0.016) was for the 70% wool-30% straw ECB treatment at I-86 (Table 10). This was the only result after the second growing season that indicated that wool ECBs might help reduce weedy species canopy cover.

Table 10. Comparison of mean percent canopy cover of weedy species between 2019 and 2020 at both experimental sites.

Site	Treatment	2019 Mean (%)	2020 Mean (%)	t	df	p-value	% Change
I-86	B	90.46	96.8	-2.45	64	0.992	7
I-86	BS	85.72	93.88	-2.40	89	0.990	10
I-86	CCBB	92.68	91.26	0.33	96	0.371	-2
I-86	W100	90.46	95.92	-1.71	75	0.954	6
I-86	W30S70	82.3	84.16	-0.39	98	0.651	2
I-86	W50S50	90.38	94.46	-1.08	87	0.858	5
I-86	W70S30	92.42	82.56	2.19	79	0.016	-11
US-30	B	41.96	68.24	-5.09	98	1.000	63
US-30	BS	43.58	65.86	-4.32	98	1.000	51
US-30	CCBB	63.82	62.92	0.19	98	0.426	-1
US-30	W30S70	59.36	71.68	-2.61	98	0.995	21
US-30	W50S50	51.58	73.8	-4.53	98	1.000	43
US-30	W70S30	62.22	69.5	-1.44	98	0.924	12

Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool - 50% straw ECB over broadcast seed mix; W30S70 = 30% wool - 70% straw ECB over broadcast seed mix; t = t-score from statistical test; df = degrees of freedom.

4.3.3.4 2020 Summary of Vegetation Results

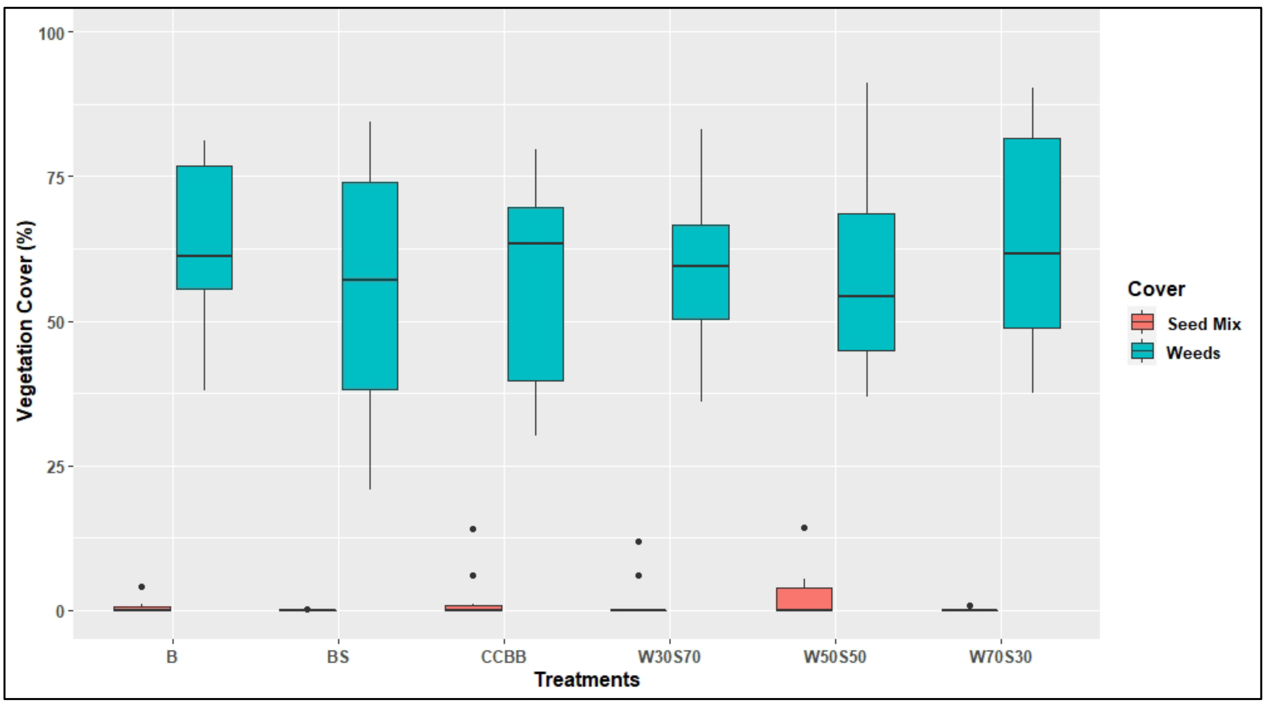
1. The increase in seed mix species' mean canopy cover and the decrease in weedy species canopy cover from 2019 to 2020 in the 70% wool-30% straw ECB treatment was statistically significant for the I-86 experimental site.
2. The seed mix species' mean percent canopy cover increased from 2019 to 2020 for all ECB treatment types, various wool-straw ECB types and the coir-straw ECB treatment. Some increases in mean percent canopy cover were up to 20-times greater.
3. Combined, the results of the second growing season with large mean percent canopy cover for seed mix species and the significant reduction of weeds in the 70% wool-30% straw ECB treatment, provided enthusiasm for a no cost extension for a third growing season. If similar canopy cover increases would occur for seed mix species and decreases for weedy species between Year 2 and Year 3, the experiment using wool ECBs might prove successful.

4.3.4 Vegetation Results in 2021

The vegetation data was collected at the end of June for the third growing season (2021). Results indicate that the seedlings that had established in 2019 and 2020 from the seed mix were mostly dead. This was most likely the result of the lack of rainfall preceding the sampling of vegetation; there was less than half of the normal precipitation for the three months preceding the sampling. Only weedy species were successfully present and alive, with limited amounts of the seed mix species mean percent canopy cover remaining on most ECB treatments. After comparing all the treatments at both sites, no statistical evidence was found to identify differences in mean canopy cover for any of the vegetative groups for any of the various types of ECBs and the three different control types.

4.3.4.1 US-30 Experimental Site

The mean percent canopy cover of the seed mix species was highest for the 50% wool- 50% straw ECB treatment when compared to the other treatments at US-30 (Figure 24). Total weedy species mean percent canopy cover was high across all types of ECBs and the control treatments, ranging from 55.7% to 64.1% (Figure 24). Based on p-values from the statistical analyses, there are no statistically significant differences (p-value < 0.05) for the mean percent canopy cover of seed mix or weedy species between the different ECB treatments or control types and thus are not displayed.

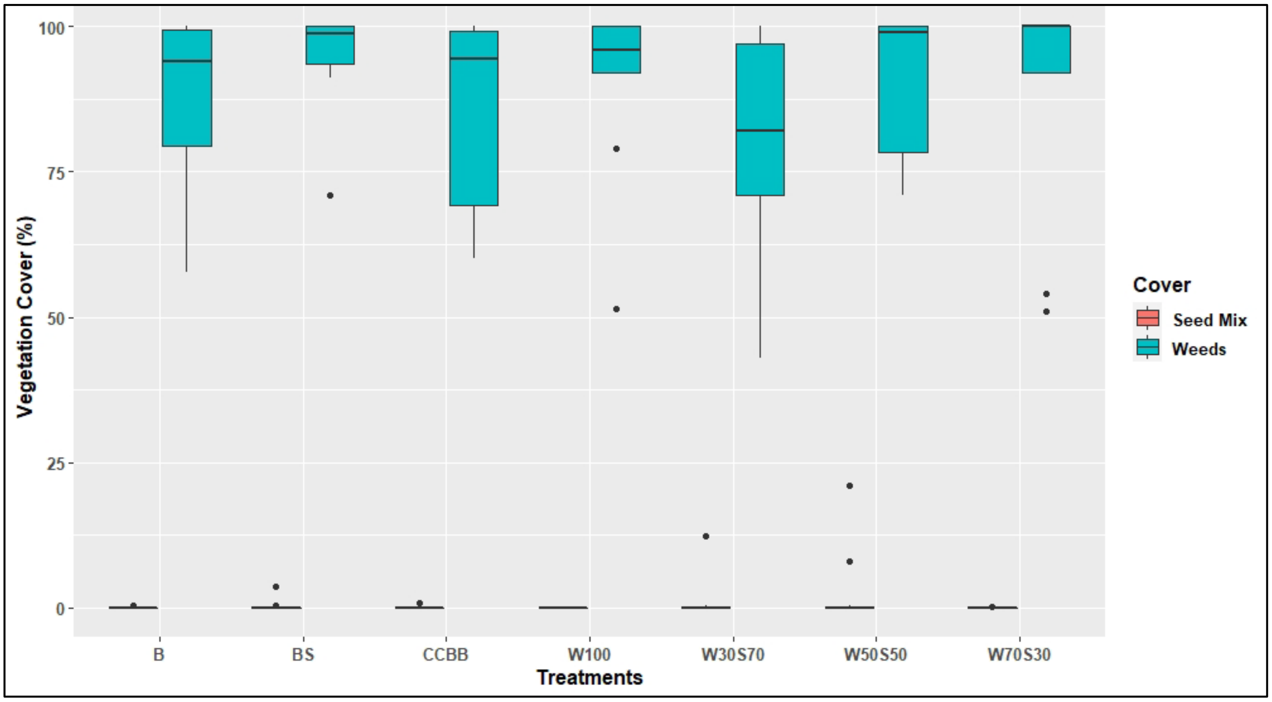


Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W70S30 = 70% wool to 30% straw ECB over broadcast seed mix; W50S50 = 50% wool to 50% straw ECB over broadcast seed mix; W30S70 = 30% wool to 70% straw ECB over broadcast seed mix.

Figure 24. Mean vegetative canopy cover of seed mix (pink boxes) and weedy species (blue boxes) at US-30 experimental site in 2020. Weedy species comprise a greater percentage of vegetation cover than seed mix species.

4.3.4.2 I-86 Experimental Site

The mean percent canopy cover of the seed mix species was highest in the 50% wool-50% straw ECB treatment (2.9%) at the I-86 experimental site (Figure 25). Total weedy species mean canopy cover was very high and ranged from 79.9% to 98.7% (Figure 25). Based on p-values from the statistical analyses, there were no statistical differences (p-value < 0.05) for the mean percent canopy cover of seed mix or weedy species between the different treatment types and thus are not displayed.



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool - 50% straw ECB over broadcast seed mix; W30S70 = 30% wool - 70% straw ECB over broadcast seed mix.

Figure 25. Mean vegetative canopy cover of seed mix and weedy species at I-86 experimental site in 2021. Weedy species comprise a greater percentage of vegetation cover than seed mix species.

4.3.4.3 2020-2021 Canopy Cover Comparison

A two-sided t-test (for increases or decreases) was conducted to identify if there were any statistical differences in the mean percent canopy cover for seed mix and weedy species between 2020 to 2021. The drought had a negative impact on seed mix species' survival and plant growth in 2021. The results in Table 11 are a comparison of mean percent canopy cover of seed mix species between 2020 and 2021. Almost all treatments at both highway experimental sites show a decrease in the mean percent canopy cover, while the seed mix species in the 100% wool ECB treatment plots were completely killed.

Decreases in seed mix species canopy cover for three of the ECB treatments were statistically significant. Two wool ECB treatments had small increases in seed mix mean percent canopy cover, but neither were statistically meaningful.

Table 11. Comparison of mean percent vegetative canopy cover of seed mix species from 2020 and 2021.

Site	Treatment	2020 Mean (%)	2021 Mean (%)	t	df	p-value	% Change
I-86	B	0.26	0.04	-1.46	56	0.150	-85
I-86	BS	0.32	0.4	0.23	72	0.816	25
I-86	CCBB	3.64	0.08	-1.70	49	0.095	-98
I-86	W100	0.26	0	-1.39	49	0.171	-100
I-86	W30S70	5.1	1.32	-1.41	72	0.161	-74
I-86	W50S50	2.62	2.94	0.13	97	0.900	12
I-86	W70S30	6.9	0.02	-3.02	49	0.004	-100
US-30	B	2	0.62	-1.42	70	0.160	-69
US-30	BS	1.48	0.02	-2.78	49	0.008	-99
US-30	CCBB	2.36	2.12	-0.13	97	0.895	-10
US-30	W30S70	1.26	1.8	0.31	98	0.755	43
US-30	W50S50	4	2.52	-0.65	95	0.517	-37
US-30	70W30S	3.02	0.16	-2.02	50	0.049	-95

Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; 100W = 100% wool ECB over broadcast seed mix; 70W30S = 70% wool - 30% straw ECB over broadcast seed mix; 50W50S = 50% wool - 50% straw ECB over broadcast seed mix; 30W70S = 30% wool - 70% straw ECB over broadcast seed mix; t = t-score from statistical test; df = degrees of freedom.

The drought in 2021 also caused weedy species' mean canopy cover to decrease compared to 2020, across every ECB and control treatment type, except two (Table 12). Comparison of mean percent vegetative canopy cover of weedy species from 2020 and 2021. The two exceptional treatments with increases in weedy species' mean percent canopy cover were not statistically significant.

Table 12. Comparison of mean percent vegetative canopy cover of weedy species from 2020 and 2021.

Site	Treatment	2020 Mean (%)	2021 Mean (%)	t	df	p-value	% Change
I-86	B	96.8	88.12	-3.26	63	0.002	-9
I-86	BS	93.88	94.88	0.37	97	0.713	1
I-86	CCBB	91.26	85.66	-1.28	96	0.205	-6
I-86	100W	95.92	91.72	-1.23	71	0.223	-4
I-86	30W70S	84.16	79.92	-0.80	95	0.423	-5
I-86	W50S50	94.46	90.72	-1.05	91	0.299	-4
I-86	70W30S	82.56	98.68	1.51	64	0.136	20
US-30	B	68.24	62.4	-1.19	98	0.238	-9
US-30	BS	65.86	55.68	-1.89	96	0.062	-15
US-30	CCBB	62.92	56.38	-1.29	97	0.199	-10
US-30	30W70S	71.68	59.3	-2.78	96	0.007	-17
US-30	W50S50	73.8	57.48	-2.80	90	0.006	-22
US-30	70W30S	69.5	64.12	-1.10	98	0.276	-8

Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; 100W = 100% wool ECB over broadcast seed mix; 70W30S = 70% wool -30% straw ECB over broadcast seed mix; 50W50S = 50% wool - 50% straw ECB over broadcast seed mix; 30W70S = 30% wool - 70% straw ECB over broadcast seed mix; t = t-score from statistical test; df = degrees of freedom.

4.3.4.4 Cheatgrass establishment and growth

Across all three growing seasons, and in both ECB experimental plots and control plots, cheatgrass dominated the mean percent canopy cover at both experimental sites (Figure 26 and Figure 27). Over the three years, there was generally an increase in mean percent canopy cover. Half of the treatments (three) conformed to this general trend at the US-30 experimental site and five of the seven treatments at the I-86 experimental site.

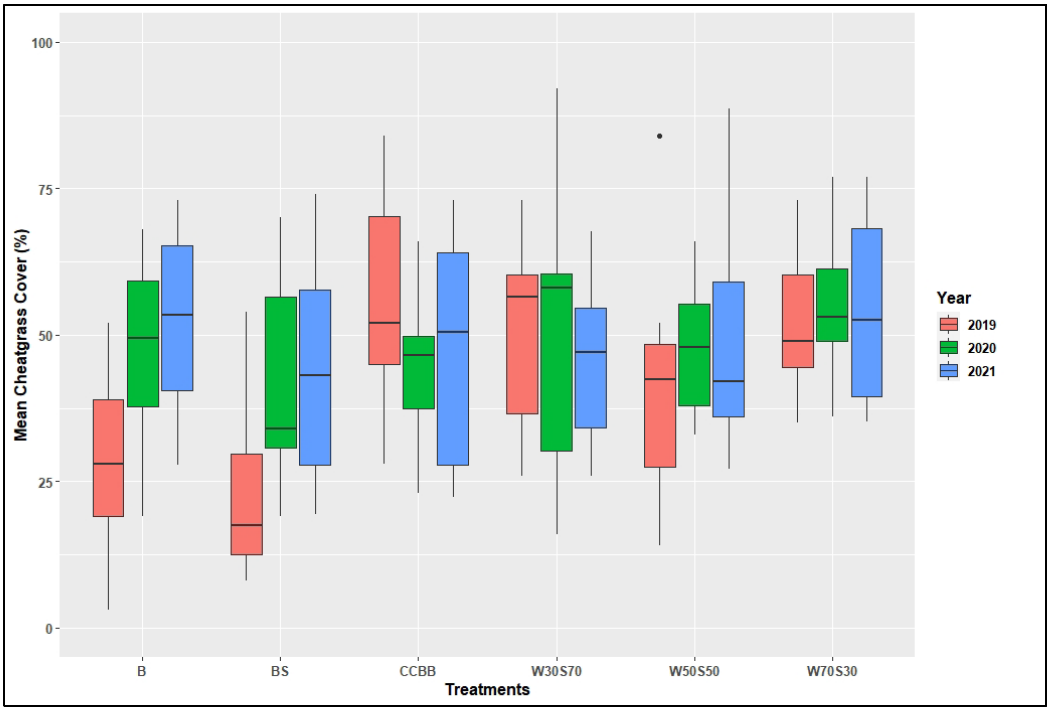


Figure 26. Mean cheatgrass cover along US-30 for 2019 (pink boxes), 2020 (green boxes), and 2021 (blue boxes)

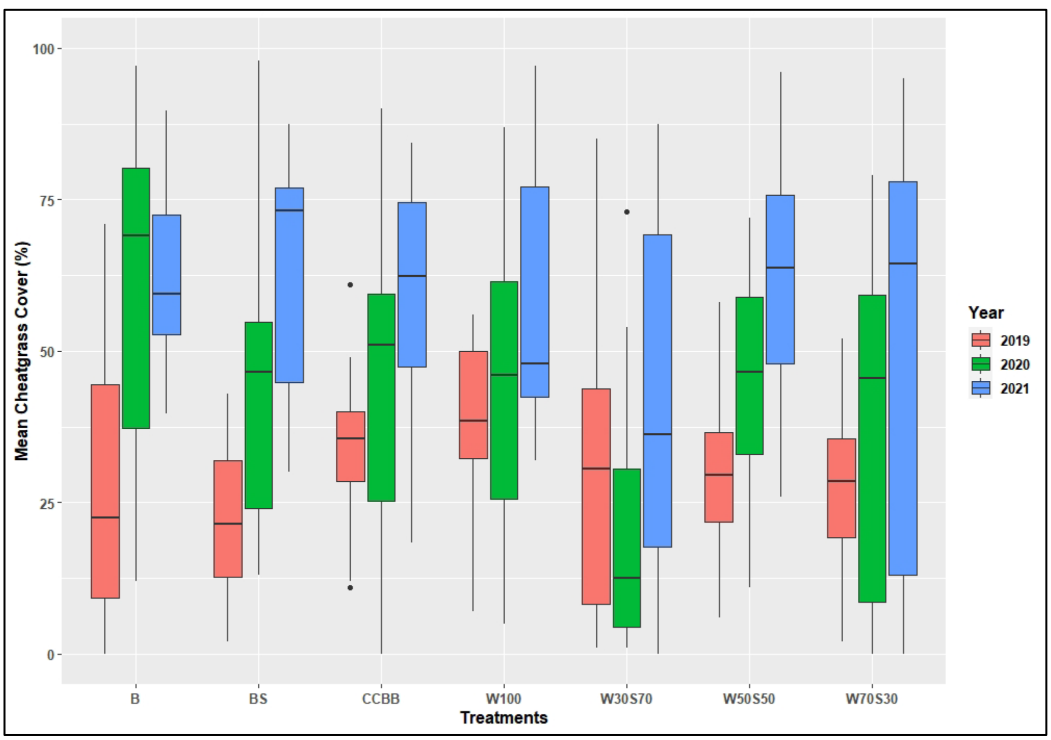


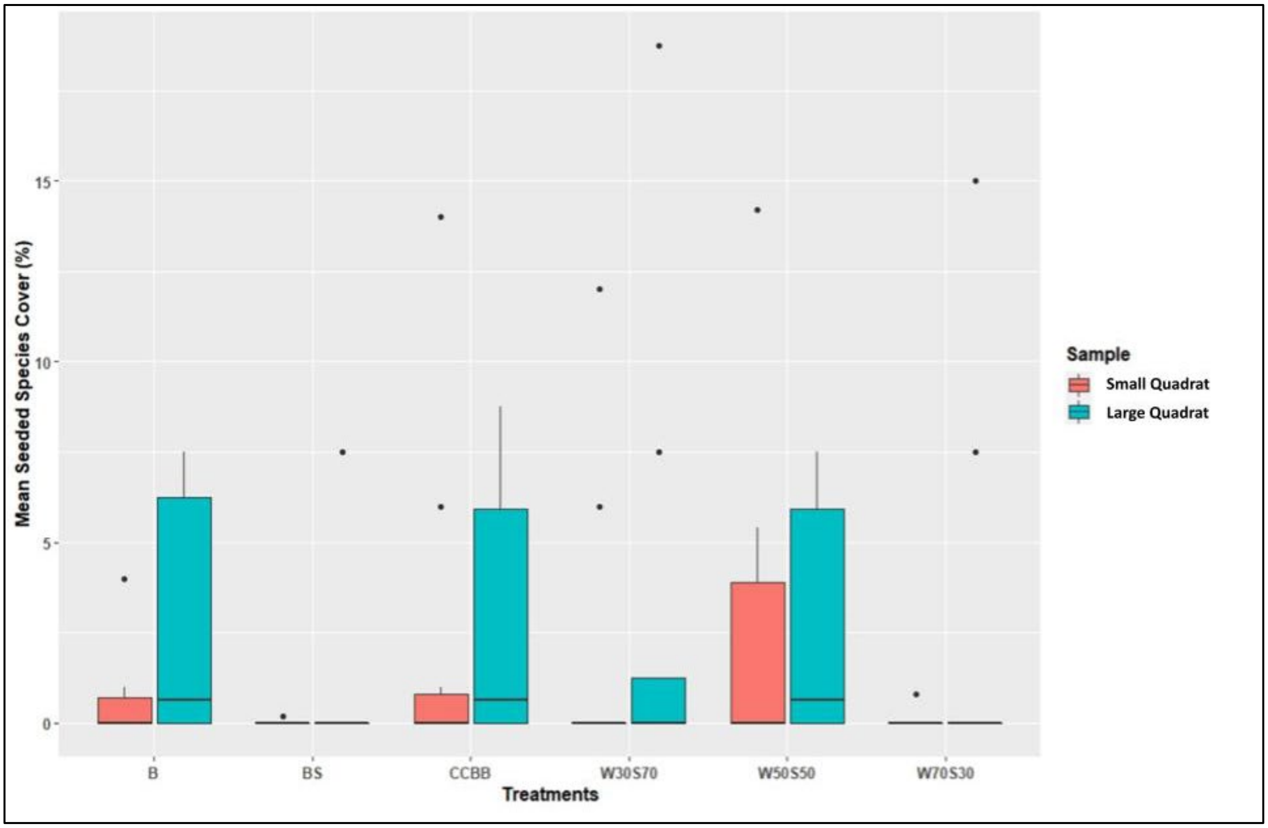
Figure 27. Mean cheatgrass cover along US-30 for 2019 (pink boxes), 2020 (green boxes), and 2021 (blue boxes).

4.3.4.5 Comparison of quadrat size

A test of quadrat size in 2021 sought to determine whether the irregular distribution of the seed mix species seedlings across the experimental plots could be better captured with 2 large quadrats (1 m^2) compared to five small quadrats (20 cm by 50 cm) randomly placed on each experimental plot. It was hypothesized that the use of the larger quadrats would reduce the variance of the mean canopy cover for each of the vegetative groups, resulting in more statistically significant differences in the mean canopy cover between the various pair-wise t-tests of the vegetative groups, for each of the treatments.

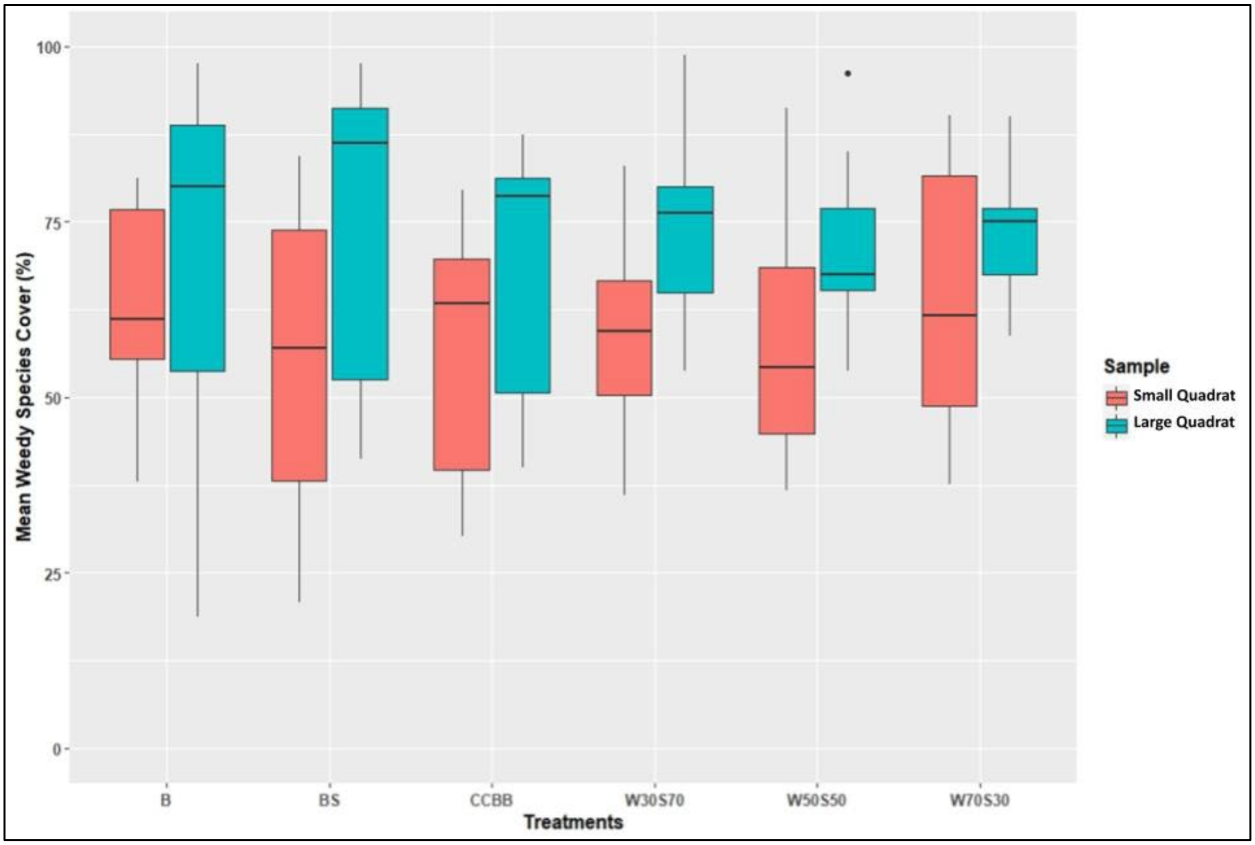
US-30 Experimental Site

The use of the large quadrats resulted in slightly higher mean canopy cover values for all three treatments with measurable seed mix species mean canopy cover at the US-30 (Figure 28). There was a higher proportion of larger values in the large quadrats compared to the small quadrats, even though the means are not that much higher (Figure 28). The large quadrats had higher mean weedy species mean canopy cover (all exceeding 10% or more) across all six treatments at the I-30 experimental site (Figure 29).



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W70S30 = 70% wool to 30% straw ECB over broadcast seed mix; W50S50 = 50% wool to 50% straw ECB over broadcast seed mix; W30S70 = 30% wool to 70% straw ECB over broadcast seed mix.

Figure 28. Comparison of mean canopy cover of seed mix species in the same experimental plots at the US-30 experimental site in 2021; one using two large quadrats (blue boxes) and the other using five small quadrats (pink boxes).

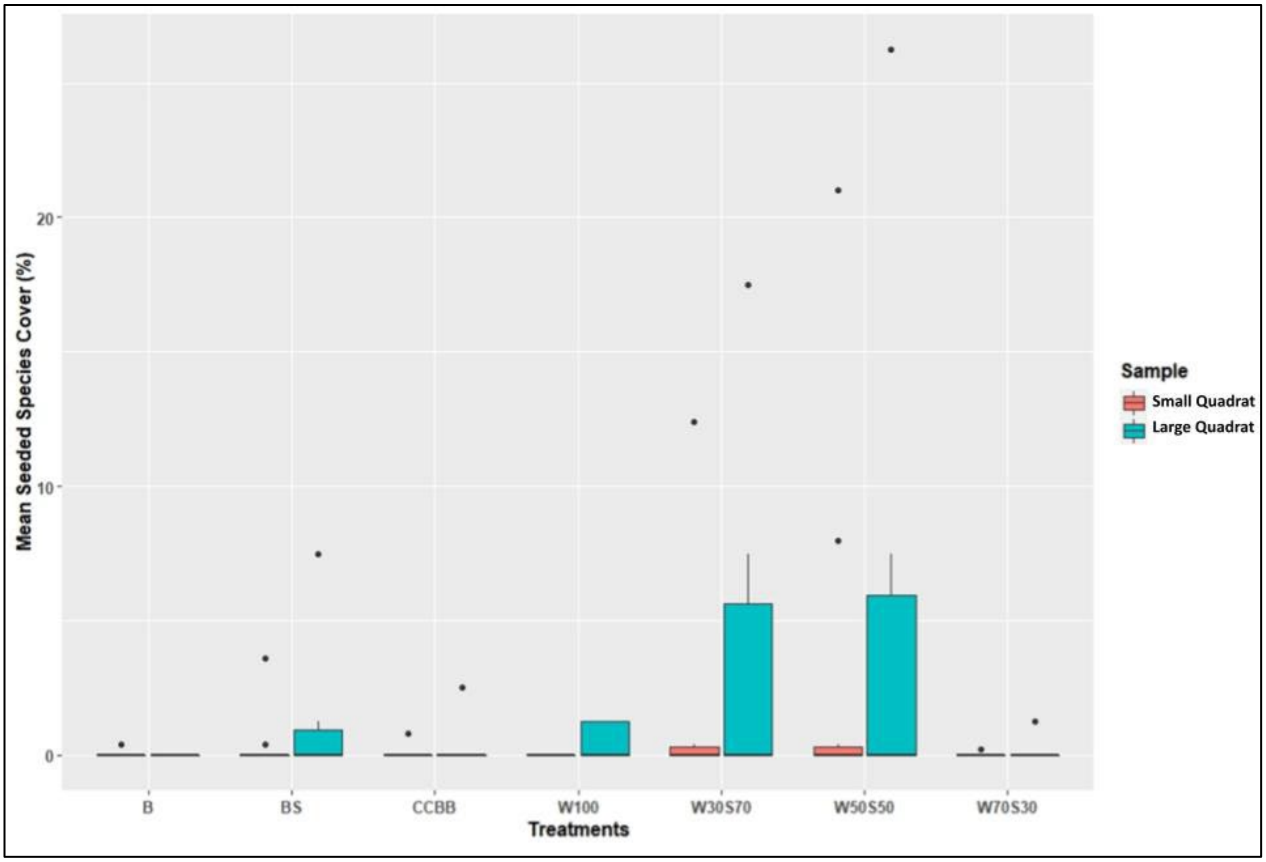


Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W70S30 = 70% wool to 30% straw ECB over broadcast seed mix; W50S50 = 50% wool to 50% straw ECB over broadcast seed mix; W30S70 = 30% wool to 70% straw ECB over broadcast seed mix.

Figure 29. Comparison of mean canopy cover of weedy species from the same experimental plots, one using two large quadrats (blue boxes) and the other using five small quadrats (pink boxes), at the US-30 experimental site in 2021.

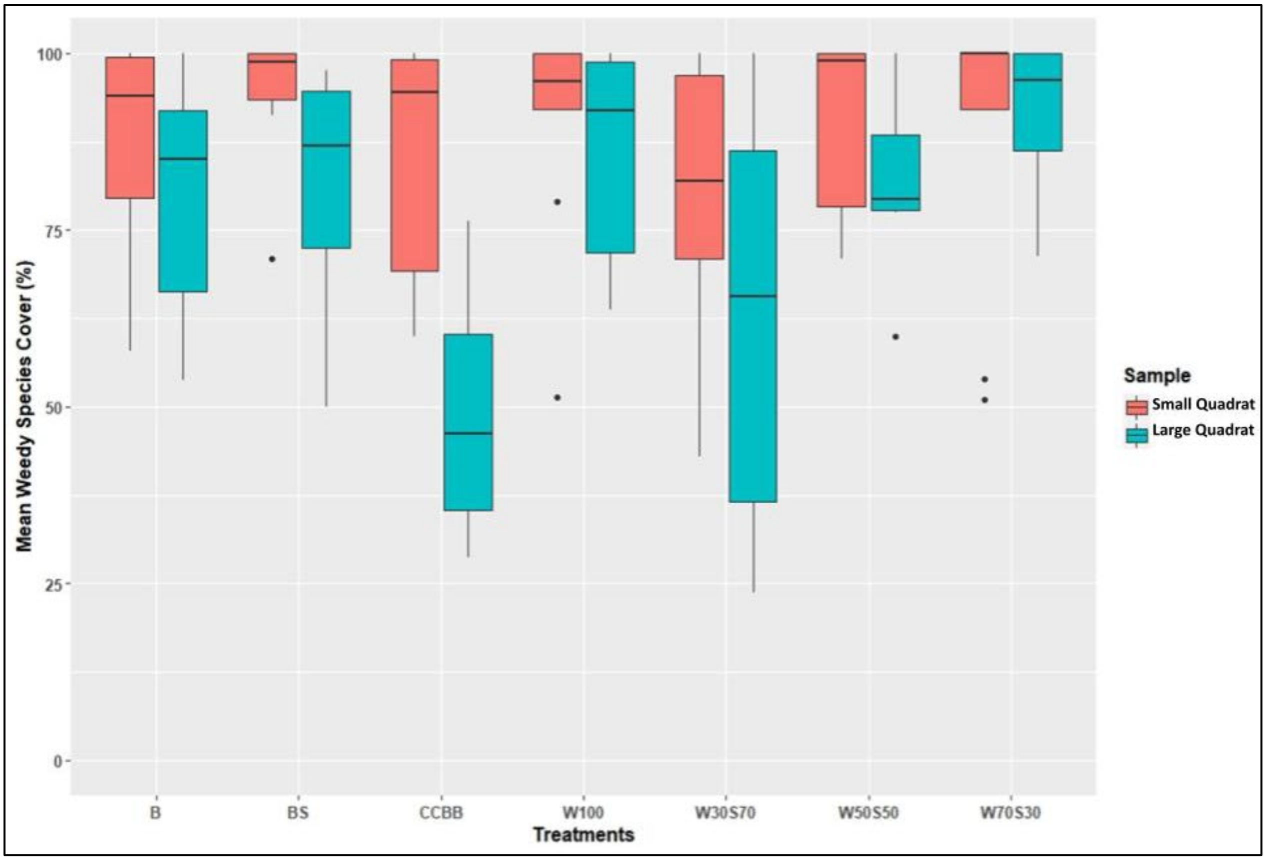
I-86 Experimental Site

The mean canopy cover for seed mix species was very similar regardless of the quadrat size at the I-86 experimental site (Figure 30). Like US-30, there was a higher proportion of larger values in the large quadrats compared to the small quadrats. Unlike US-30, the mean canopy cover of weedy species was *lower* across all seven treatment types for the large quadrats (Figure 31). The differences were much more variable than US-30 —from less than a 10% difference between means to nearly a 50% difference.



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool - 50% straw ECB over broadcast seed mix; W30S70 = 30% wool - 70% straw ECB over broadcast seed mix.

Figure 30. Comparison of mean canopy cover of seed mix species in the same experimental plots, one using two large quadrats (blue boxes) and the other using five small quadrats (pink boxes), at the I-86 experimental site in 2021.



Notes: B = Bare Soil, BS = Bare Soil with broadcast seed mix; CCBB = Coconut-Straw ECB over broadcast seed mix; W100 = 100% wool ECB over broadcast seed mix; W70S30 = 70% wool-30% straw ECB over broadcast seed mix; W50S50 = 50% wool - 50% straw ECB over broadcast seed mix; W30S70 = 30% wool - 70% straw ECB over broadcast seed mix.

Figure 31. Comparison of mean canopy cover of weedy species from the same experimental plots, one using two large quadrats (blue boxes) and the other using five small quadrats (pink boxes) at the I-86 experimental site in 2021.

Despite the differences of the mean percent canopy cover of seeded or weedy species that resulted in the use of the different quadrat sizes, the larger quadrats did not result in increases in the probability that the differences between mean canopy cover between treatments were significant. Thus, there was no advantage of using the larger quadrats to increase the ability to determine if differences in mean canopy cover between the various vegetative groups, using pair-wise t-tests, were statistically significant.

2021 Key Findings

1. The drought of 2021 had negative impacts on plant growth across all species and treatments. It resulted in the loss of seed mix species' seedlings and for some treatments, all seed mix species succumbed to the drought. This made it impractical to determine if wool ECBs perform better than the typical coir-straw ECB, and if so, how well. Similarly, it made it difficult to determine if weedy canopy cover was lower under the different wool ECB treatments compared to the coir-straw ECB.

2. The mean canopy cover of the seed mix species was nearly equal regardless of whether a large or small quadrat was used for sampling. Although the means were similar, large quadrats captured higher cover values more frequently. The differences in mean weedy species' canopy cover among treatments was higher across all treatment types at the US-30 experimental site using the large quadrat and lower across all types at I-86 for the large quadrat, providing confounding results. There was no improvement in determining if the differences in mean percent canopy cover were significantly different using large quadrats compared to using small quadrats to sample the experimental plots

5. Value of Waste Wool as a Nitrogen Fertilizer

One advantage of wool over coir fibers is that pure wool is comprised of approximately 16%-17% nitrogen, which is an important plant macronutrient. Often when highway construction alters or removes the topsoil along the roadway, nitrogen, other macronutrients, micronutrients, and organic matter, are added to the soils to ameliorate the disturbed soils and prepare the roadside for seedling establishment. Often, transportation departments rely on commercially available fertilizers and compost that can be broadcast before a site is seeded and the ECBs are placed over the seeded and fertilized cut slopes.

For those highway roadside restoration sites where nitrogen is lacking, the other macronutrients are not, and OM is sufficient, such as the I-86 and US-30 experimental sites in this project, a nitrogen fertilizer may be the only soil amendment needed. The most common nitrogen fertilizers commercially available in the US are anhydrous ammonia (82% nitrogen), urea (44%-46% nitrogen), urea ammonium nitrate solutions (28%-32% nitrogen), ammonium nitrate (34% nitrogen), and anhydrous ammonia (82% nitrogen) (Vitosh et al. 1995). Since anhydrous ammonia must be injected into the soil, this often is not used for roadside applications, particularly on steep cut slopes where ECBs are used.

The wool in woolen ECBs may serve to provide nitrogen for plant establishment and growth and preclude the need to pay for commercial nitrogen fertilizer and its application on roadside cut slopes. Based on the amount of wool in the wool-straw ECBs used in this project, it may be possible for the woolen ECBs to replace the need for fertilizing if soil tests indicate a need for nitrogen. The amount of nitrogen made available for plant growth as the wool decomposes in the ECBs is significant. Table 13 provides the amount of nitrogen calculated for each of the ECB blankets used at the ITD experimental sites, based on the wool weights in Table 2. The pure wool ECB, which was not measured, is based on 271 g (8 oz) of wool for each square meter.

Table 13. The amount of nitrogen in the wool component of the erosion control blankets from this study and the projected amount of nitrogen it contains based on wool being comprised of 16% N.

Wool Erosion Control Blanket Type	Amount of wool[1] (g/m^2)	Amount of Nitrogen (g/m^2)	Amount of Nitrogen (lb/acre)
100% wool	226	36.2	323
70% wool - 30% straw	168.6	27.0	241
50% wool - 50% straw	102.7	16.4	147
30% wool - 70% straw	82.1	13.1	117

[1]weights are from Table 2 and 100% wool is based on 8 oz of wool in the ECB's fill per square yard.
[2]g/m^2 = grams/square meter

Another advantage of wool in the ECB matrix is that it slowly decomposes (Zheljazkov, 2005), allowing the nitrogen to be available for plant growth over multiple growing seasons. Observational evidence from this study indicated that slight amounts of wool remained in some ECBs after three growing seasons. Zheljazkov (2005) reported that wool incorporated into the soil decomposed within two to four growing seasons.

The results from the bulk soil samples collected at the two experimental sites indicate that both the I-86 and US-30 experimental sites had adequate amounts of organic matter (OM) at the beginning of the experiment; 3.2% OM and 7% OM, respectively (Table 7). Knowing the OM percentages in the soil helps adjust nitrogen fertilization rates. The University of Idaho (U of I) Extension's publication uses levels of OM at 0 - 1.5%, 1.5%-3.0%, and greater than 3.0% OM to adjust nitrogen fertilizer rates based on the amount of nitrate in the soil (Moore et al. 2011).

Nitrate levels measured for this study at the I-86 site were 27 mg/kg, and at US-30 they were 7 mg/kg. Both sites' nitrate levels were well under 60 mg/kg recommended by Moore and others (2011), suggesting that nitrogen fertilizer could enhance plant growth at these sites.

Based on the University of Idaho Extension's guide, for nitrate levels less than 10 mg/kg, soils require 3 lb of nitrogen per 1,000 square feet to enhance lawn (grasses) with OM percentages at 3% or above. For the I-86 experimental site, to enhance any type of plant growth, it is recommended that 0.5 lb/acre be added to soils with high OM levels. Table 14 shows calculated estimates of 22 lb/acre of nitrogen fertilizer for the I-86 experimental site, and 130 lb/acre at the US-30 experimental site.

Table 14. Calculations for nitrogen fertilizer needed to enhance plant growth at the two experimental sites to the standard of agricultural or horticultural plants.

Experimental Site	Organic Matter (%)	Nitrate (mg/kg)	Recommended Amount of Nitrogen Fertilizer (lb/1000 ft^2)	Recommended Amount of Nitrogen Fertilizer (lb/acre)
Interstate 86	3.2	27	0.5	22
US Highway 30	7	7	3	130

It should be noted that natural plant communities require significantly less soil fertility than agricultural or horticultural crops for which the calculations in Table 14 were made. District 5 roadside contractors stated that typical ITD projects require 10-35 lb of nitrogen fertilizer, and the fertilizer is not combined with the seed mix; therefore, fertilization is a separate, additional operation. Calculations from Table 14 indicate that the use of any of the wool ECBs used in this experiment would provide enough nitrate to meet fertilization needs at both sites as well as for other ITD projects where nitrogen is needed and other soil amendments are not. Thus, the use of wool ECBs could preclude the need to pay for nitrogen fertilizer and its application by a contractor for cut slopes using wool ECBs.

6. Discussion

6.1 Wool ECB Performance

Seed Mix Species' Establishment and Growth

As expected, the first growing season had very low mean percent canopy cover for seed mix species for any of the wool ECB treatments or control plots. By the second growing season (2020) some of the wool ECB treatments had seed mix species mean percent canopy cover increase up to 20-fold over the first year (Table 9). The seed mix species mean canopy cover increased from 2019-2020 for all ECB treatment types—the various wool-straw ECB types and the coir-straw ECB treatment. This provided promise that further increases in the amounts of canopy cover by the seeded native perennial grasses would continue to make inroads against the weedy species in the subsequent and final year of the experiment. This was also based on the results of the third growing season in the Montana roadside experiment, where several wool ECB treatments' seed mix species mean percent canopy cover exceeded 20 % (Ament et al. 2017). Thus, promising seedling establishment and growth from the seed mix species resulted in a no cost extension to add a third growing season to measure vegetation, and to seek conclusive results.

The third growing season (2021) was unusually dry, with only 1.75 in (4.4 cm) of precipitation recorded during the months of April, May and June at the Pocatello, ID weather station. Normal precipitation for these three months in Pocatello is approximately four inches (10.2 cm). It appears that the drought may have killed the young seedlings from the seed mix in some treatments or the canopy cover was reduced significantly. Only three wool ECB treatments across the two experimental sites had a measured increase in seeded species' mean percent canopy cover between 2020 and 2021, and none of the increases were statistically meaningful, all p-values were above 0.05 (Table 11; Table 12). The third growing season made it difficult to conclude that any of the four different wool ECBs outperformed the standard coconut-straw ECB at either experimental site.

Weed Suppression by ECBs

Weedy species mean percent canopy cover was very high throughout the study under all ECBs and control plots. At the I-86 experimental site in Year 1, weedy species mean percent canopy cover among ECB treatments ranged from 82-92% and increased in Year 2, ranging from 84-94%. The exception was the 70% wool-30% straw ECB, with which weedy species experienced a statistically significant 11% decrease in mean percent canopy cover. During the dry third growing season, weedy species mean percent canopy cover decreased across all treatments except on the 70% wool-30% straw ECB (20% increase) and bare soil (1% increase). Thus, weeds dominated the I-86 experimental site, and only the 70% wool-30% straw ECB showed promise at limiting weedy species cover; but, the drought in 2021 reversed reductions made in 2020.

Under the wool ECBs at the US-30 experimental site, weedy species mean percent canopy cover varied from 51-63% in 2019 and increased under all types of wool ECBs, in the range of 69-74% in 2020. Again, in the growing season of 2021, all three wool ECB types, as well as all control treatments, had decreases in mean percent canopy cover of weedy species. These decreases were attributed to the lack of rain; none were statistically significant.

Changing quadrat size for sampling

In an effort to decrease sampling variability and increase statistical power to determine meaningful differences in mean percent canopy cover among vegetative groups across the different treatments, two large quadrats (1 m^2) were randomly placed on each experimental plot and their results were compared to the results from the five randomly place small quadrats (20 cm by 50 cm). The large quadrat sampling did not improve statistical evidence that the differences in vegetative group means were significant.

Erosion Control

There was no evidence of erosion at either of the experimental sites, for any of the ECB treatments, or the control plots. This was the result of high vegetative canopy cover that established in the first year and continued through the third year at both experimental sites. The vegetation was dominated by weedy species. Most of the experimental plots had 90% or greater canopy cover contributed jointly by weedy and seed mix species on each experimental plot.

Soil Fertility

Before the experimental plots were established, the soil conditions at each highway experimental site were generally favorable for plant growth. The soils exhibited slightly basic pH levels, low sodium values, an adequate amount of organic matter, and adequate levels of the macronutrients, except for nitrogen, which was slightly lacking.

It was difficult to determine whether the wool ECBs increased nitrogen in the soils at either of the two highway experimental sites, most likely due to soil data variability. Since nitrate is soluble and thus highly mobile in soil columns (Follett 1995), most of the nitrogen released by the decomposition of wool may be undetectable in the bulk soil samples, as it is either consumed by growing plants and/or flushed through the soil by rain and melting snow.

Some studies promote caution when adding nitrogen fertilizer to soils in areas infested by non-native annual grasses such as cheatgrass. He et al. (2011) found that additions of nitrogen to the soil increased cheatgrass competitiveness, while not improving native species ability to compete. Brooks (2003) found increasing soil nitrogen allowed non-native grasses to dominate in a Mojave Desert experiment. Similarly, Vasquez et al. (2008) found cheatgrass competitiveness increased with soil nitrogen. Thus, large applications of nitrogen at the beginning of a restoration project could help cheatgrass dominate sites. Alternatively, the slow release of nitrogen to the soil by the decomposition of wool from the wool ECBS over the three years of the experiment, may have made nitrogen available to the native seed mix species for their establishment and growth.

The amount of nitrogen produced by wool ECBs is adequate to meet fertilization needs of nitrogen deficient soils. The amounts of nitrogen vary, depending on the amount of wool in the ECB; however, the lowest amount of wool in an ECB type in this study, the 30% wool-70% straw ECB, would provide 117 lb nitrogen per acre as the wool decomposes. Assuming it takes three years to decompose, that is nearly 40 lb nitrogen per acre per year.

7. Costs and Benefits of Wool Erosion Control Blankets

7.1 Introduction

The overall objective of this chapter is to determine if the cost of wool-straw ECBs, with their differing amounts of wool in the fill material, are cost efficient investments compared to a coir-straw ECB. Either type of ECB supports the establishment and growth of native plants, reduces soil erosion, and is composed of natural fibers that decompose. Therefore, delineating the costs and benefits of wool-straw ECBs compared with coir-straw ECBs may offer alternative materials for ITD's consideration and use for roadside restoration projects.

Several advantages of wool-straw ECBs are:

1. They contain fill material that can be produced in Idaho and other US states, rather than imported from tropical countries where coconut plantations are managed. Thus, supply chains for wool-straw ECBs are less vulnerable to disruption than coir-straw ECBs
2. They provide market demand for lower quality or waste wool. They provide a use and economic value for wool that is rejected by clothing and blanket manufacturers or is of poor quality for other types of textile or industrial products.
3. Since wool fibers are comprised of 16%-17% nitrogen, the wool in the ECBs could replace the need to fertilize those roadside cut slopes with inadequate soil fertility. In addition, wool decomposes over several years, so nitrogen is slowly released for plant utilization, which is different than typical practices where a single application of nitrogen fertilizer primarily supports the first year of roadside vegetation establishment and growth. Wool ECBs would provide an alternative to the use of a nitrogen fertilizer, particularly in cheatgrass dominated areas, where the exotic annual grass would benefit from a high pulse of nitrogen from fertilizer to the detriment of native species.

7.2 Calculations of Cost Using Various ECBs

A steep roadside cut slope is typically protected after construction through a four-step process, 1) preparation of the site with topsoil or other seed bed media, 2) broadcasting a seed mix specifically designed for the site, 3) fertilization, calculated specifically for the needs of the site, and 4) coverage of soils, seeds, and fertilizer with ECBs and pinning them to the soil to prevent slippage or wind removal. The use of wool ECBs as a fertilizer could allow ITD to forgo the costs of a separate operation for contractors to fertilize cut slopes during post-construction revegetation.

Following are the economic costs and benefits of using wool ECBs on ITD's steep cut slopes, particularly on those slopes that require ECBs and nitrogen fertilizer. It is assumed that the cost to install wool-straw or coir-straw ECBs are the same, so that the only cost difference is the cost of ECB product.

The cost of fertilizing a typical ITD reclamation project was estimated using ITD data from contract bids. Based on a review of the fertilization costs for 43 projects in District 5, in the years 2014-2021, mean bid values to fertilize ITD projects averaged $1,386/acre or $.034/m^2 (ITD business website, “average unit price reports”, online at: https://itd.idaho.gov/business/). The database did not differentiate or describe the type of fertilizer used or its application method (e.g., broadcast, drilled). The prices for the standard coir-straw ECB, various wool ECBs, and the average cost of ITD fertilization in District 5 are described in Table 15.

Table 15. Product costs for erosion control blankets and fertilizer.

Product[1]	Metric Unit Cost[2] US Dollars/m^2	English Unit Cost US Dollars/acre
70% Straw-30% Coir ECB	0.62	2,509
100% Wool ECB	2.69	10,886
50% Straw-50% Wool ECB	1.18	4,775
75% Straw-25% Wool ECB	0.84	3,399
Application of fertilizer	0.34	1,388

*ECB = Erosion Control Blanket

Costs for ECBs from Ament et al. 2017, Average fertilizer costs based on ITD business contracts, 2014-2021

7.3 Cost comparison of using different ECB products

An estimation of the different costs of fertilizing and applying the standard 70% straw-30% coir ECB or applying only a wool-straw ECB that decomposes and provides nitrogen in lieu of fertilizing, is presented in Table 16. The 25% wool-75% straw ECB would be more cost effective ($3,399/acre) than the current standard practice of fertilizing and using a coir-straw ECB which is estimated to cost $3885/acre (Table 16). If a 50% wool-50% straw ECB was selected, with an estimated price of $4,775/acre, it would only be 23% more costly than the coir-straw ECB with nitrogen fertilizer applied (Table 16).

Table 16. Estimated costs of applying fertilizer or using wool ECBs to deliver nitrogen fertilizer.

ECB Method	Cost of Applying Nitrogen Fertilizer (US Dollars/m^2)	ECB Metric Unit Cost (US Dollars/m^2)	Total Metric Unit Cost (US Dollars/m^2)	Total English Unit Cost (US Dollars/acre)
70% Straw-30% Coir ECB and Fertilize	0.34	0.62	0.96	3,885
100% Wool ECB	na	2.69	2.69	10,886
50% Straw-50% Wool ECB only	na	1.18	1.18	4,775
75% Straw-25% Wool ECB only	na	0.84	0.84	3,399

na = not applicable

8. Conclusions

This research project constructed two random-block experiments along two highways in ITD District 5 in Idaho. It examined the establishment and growth among different vegetative groups – native perennial grasses from a broadcast seed mix, weedy forbs, weedy grasses, and other species that are not weeds but that are not found in the seed mix. Using different ratios of wool and straw in the matrix, four different wool ECBs were compared to the current practice of transportation agencies that use a coir-straw ECB for roadside vegetation reestablishment on cut slopes after construction and for other types of roadside disturbances.

During each of three growing seasons, the vegetative canopy cover of all species in the sampling quadrats was measured, summarized, and evaluated to determine if there were any differences in the performance of the different types of wool-straw ECBs, the coir-straw ECB, and the control plots.

The third year of the experiment was extremely dry, leading to a significant decline of the canopy cover of the seed mix species that had established and grown in the first two growing seasons. Conversely, in the third growing season, there were increases in mean percent canopy cover by cheatgrass at both experimental sites, although overall weedy species canopy cover decreased.

Differences in mean percent canopy cover of seed mix species and weedy species, under the different ECBs, as well as the control plots, did not achieve statistical significance in any of the three growing seasons. Some wool ECB treatments had large increases in seed mix species mean percent canopy cover between Year 1 and Year 2. Because this result showed great promise, a no cost extension allowed a third growing season to be added to the research project. Further increases were expected between Year 2 and Year 3. However, three dry three months leading up to measurements collected in the third growing season (2021) decimated many of the seed mix seedlings that had established in the first two years. Thus, results are inconclusive as to whether wool ECBs increase the establishment of seeded native perennial grasses in cheatgrass dominated ITD roadsides in southern Idaho.

Independent of the vegetative study, an analysis of the wool in the ECBs describes how it could provide significant amounts of nitrogen for plant growth, in lieu of commercial fertilizers, for cut slopes that are nitrogen deficient. In addition, unlike a single burst of nitrogen from the typical single application of a commercial fertilizer, nitrogen would be available for up to three years for plant growth via the slow decomposition of the wool.

From an economic perspective, for nitrogen deficient roadside reclamation sites with cut slopes requiring ECBs, it appears using some types of wool ECBs could be more cost effective than applying nitrogen fertilizer and covering the slopes with coir-straw ECBs.

If the use of wool-straw ECBs was broadly applied, it could create demand for waste wool ECB products, spurring their manufacture and possibly providing an economic boost to wool growers in Idaho and other states.

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