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Evaluating the efficacy of wood shreds for mitigating erosion

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Abstract

An erosion control product made by shredding on-site woody materials was evaluated for mitigating erosion through a series of rainfall simulations. Tests were conducted on bare soil and soil with 30, 50, and 70% cover on a coarse and a fine-grained soil. Results indicated that the wood product known as wood shreds reduced runoff and soil loss from both soil types. Erosion mitigation ranged from 60 to nearly 100% depending on the soil type and amount of concentrated flow and wood shred cover. Wood shreds appear to be a viable alternative to agricultural straw. A wood shred cover of 50% appears optimal, but the appropriate coverage rate will depend on the amount of expected concentrated flow and soil type.
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1. Introduction

Disturbed soils at construction, timber harvest, and post-wildfire sites are particularly susceptible to rainfall-induced erosion (Elliot and Robichaud, 2001). There have been continuing efforts to evaluate the performance of erosion control methods including tackifiers, geotextile materials, and numerous natural vegetative covers (Burroughs and King, 1989; Grace, 2002; Grismer and Hogan, 2005; Yu et al., 2003); however, agricultural straw remains one of the most widely used materials for erosion mitigation, with more than 12,500 Mg applied to forested lands in the United States in 2002 (Foltz and Dooley, 2003). Agricultural straw is typically perceived to be inexpensive, readily available, easy to apply, and effective in reducing soil loss. Foltz and Dooley (2003) estimated that more than $75 million was spent annually in the U.S. on over 250,000 Mg of agricultural straw for erosion control purposes. Recent studies, however, have highlighted some of the drawbacks of using agricultural straw. Application in forests may introduce invasive weeds (Robichaud et al., 2000) and chemical residues from agricultural pesticides have been reported in composts and straw (Michel and Doohan, 2006). Workers involved in the spreading process may be exposed to health risks, as straw carries fine dust particles that can become liberated when the straw elements are shattered (Kullman et al., 2002). Additionally, demand for its use in other applications, such as fuel production, along with its agronomic and ecologic value when left in the field, have reduced its availability and increased its cost (Bower and Stockman, 2001; Fife and Miller, 1999; Gorzell, 2001; Kline, 2000). While application of agricultural straw has proven a viable and convenient approach to reducing soil loss, there is a need for an alternative erosion control material.

One alternative erosion control material would be a woody product derived from native forest materials. A study conducted by Foltz and Dooley (2003) evaluated the performance of wood strands, a byproduct of veneer manufacturing designed with optimum dimensions for soil loss mitigation. The optimum dimensions were a width of 6 mm and a thickness of 3 mm combined with two separate lengths of 60 and 100 mm. These dimensions are controlled in the manufacturing process. Unlike agricultural straw, wood strands are inherently weed and chemical free, are not likely to carry fine dust

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particles, and are manufactured from material that would otherwise be wasted. Foltz and Dooley (2003) found that wood strands were as effective as straw in reducing runoff and sediment loss. Yanosek et al. (2006) investigated the efficacy of wood strands on various slopes and soil textures and concluded that when compared to straw, wood strands were equally effective in reducing soil loss from coarse-grained soils and superior on fine-grained soils. They also reported that the three-dimensional layering of the wood strands provided a highly stable matrix which helped to reduce soil loss and prevent rill formation.

Grismer and Hogan (2005) tested pine-needle mulch, wood chips, straw, and hydroseeding in the Lake Tahoe basin using rainfall simulation. They concluded that revegetation, or application of pine-needle mulch on both volcanic and granitic soils dramatically decreased sediment concentrations and yields. They also reported that wood chips, tillage, biosol, compost, or mulch covers together with plant seeding resulted in little or no runoff and subsequent sediment yield from both soils. Wood chips and soil rehabilitation treatments continued to result in little or no runoff 2 years after placement.

Groenier and Showers (2004) suggested the use of wood shreds for soil loss reduction. They reported that small-diameter trees removed during road construction, and woody debris from forest thinning for fuel reduction could be shredded into a mulch-like material. Typically, these materials would have to be burned or chipped to reduce fire hazard, therefore, shredding them for erosion mitigation creates a more valuable use. An additional advantage of using wood shreds is that they can be derived from on-site forest materials, especially during road construction or at fire rehabilitation sites, thus reducing transportation costs. They are similar to wood strands in that they are derived from forest materials and their use avoids the usual problems associated with agricultural straw. Unlike wood strands, however, wood shreds are not manufactured to specific dimensions. The shredding process produces a mulch-like material with a range of sizes from less than 25 mm to branches larger than 200 mm in length. Width and thickness are similarly variable.

A series of laboratory rainfall simulations were performed to test the efficacy of the wood shreds in controlling rainfall-induced soil loss. The goals were to determine the (1) relationship between cover and application rate of wood shreds, (2) impact of wood shreds on runoff, (3) impact of wood shreds on erosion, and (4) impact of wood shreds on the mean diameter of eroded sediments.

2. Methods and materials

Rainfall simulations were conducted on indoor soil plots at the U.S. Department of Agriculture (USDA) Forest Service, Rocky Mountain Research Station between February 2005 and April 2006. The effectiveness of four treatments of wood shred coverage, 0, 30, 50, and 70%, was tested on two soil types. Treatments were tested in a random order within each soil type. There were three replicates of each treatment resulting in a factorial experimental design consisting of four treatments by two soils by three replications giving a total of 24 rainfall simulations.

Tests were conducted on a coarse-grained and a fine-grained soil. Soils were chosen to be representative of the typical soil textures present in western U.S. forests. The fine-grained material had a textural classification of a sandy loam (SL) with 55% sand, 37% silt, and 8% clay. The coarse-grained material had a textural classification of a gravelly sand (GS) with 17% gravel and a gravel-free composition of 87% sand, 13% silt, and less than 1% clay.

Soil was placed in steel plots with dimensions of 1.24 m wide, 4.0 m long, and 0.2 m deep. Expanded metal with openings of 12 mm and a geotextile fabric (Phillips 6-WS) allowed water to seep out the bottom of the plot frames simulating infiltration into deeper soil horizons. The prepared plot was placed on a steel frame with a slope of 30%.

Gravimetric soil moisture content was measured before each rainfall by oven-drying soil samples at 105 °C. Soil bulk density was determined prior to rainfall using a Troxler Model 3440 nuclear gauge.

A simulated storm that produced both raindrop impact and concentrated flow was applied using a Purdue-type rainfall simulator (Foster et al., 1982) with VeeJet 80150 nozzles to deliver a raindrop size distribution and energy approximating natural rainfall (Meyer and Harmon, 1979). A rainfall rate of 50 mm h^{-1} was chosen to ensure that the entire plot area was contributing runoff and has a return period of 50 years throughout much of the Intermountain Western United States (NOAA, 1973). In addition to the simulated rainfall, concentrated flows of 1 and 4 L min^{-1} (equivalent to run-on rates of 12.1 and 48.4 mm h^{-1}, respectively) from a flow regulator were added at the top of the plot. These added flows increased the hydraulic shear of the runoff water and simulated a plot with concentrated flow from upslope (Laflen et al., 1991). Rainfall and concentrated flow combinations are referred to as 'R', '$R+1$', and '$R+4$' and are detailed in Table 1. Reporting results in this manner provides the reader with the expected runoff and sediment production from a combination of rainfall and concentrated flow conditions.

Timed grab samples taken each minute were used to determine runoff rates and sediment concentrations. A composite sample taken for a 20-s duration every minute during the $R+1$ period and a separate composite sample taken for a 10-s duration every minute during the $R+4$ period were used to characterize the particle size distribution of the sediment in the runoff. Insufficient runoff did not allow characterization

Table 1
Rainfall simulation and inflow combinations

	R	$R+1$	$R+4$
Rainfall rate (mm h^{-1})	50	50	50
Concentrated flow rate (L min^{-1})	0	0.97	4.1
Concentrated flow rate (equivalent run-on rate mm h^{-1})	0	12.1	48.4
Interval (min)	0–15	15–20	20–25

of the sediment from the rain-only period. Particle size analysis of the eroded sediment was determined by wet sieving (ASTM, 2004).

Wood shreds were produced from lodgepole pine logging slash and delivered by the Missoula Technology Development Center to the Moscow Forestry Science Lab in two lots. Material characteristics were quantified by counting pieces and measuring their mass. The first lot was used on the sandy loam and the second was used on the gravelly sand. In both cases, a measured mass of wood shreds was applied to each plot by hand prior to rainfall simulation. Wood shred coverage measurements were taken using a point-intercept grid on a clear acrylic sheet with 605 points spaced 25 mm apart. Cover points were counted at three locations (upper, middle, and lower section) on the plot and combined for a plot level average. In cases where the measured cover was more than five percentage points from the desired cover, the cover amount was adjusted by removing or adding shreds until measured cover was within five percentage points of the desired cover. Gregory's (1982) equation was used to predict cover from all mass of shreds and cover measurements.

$$C = a\left(1 - e^{-bM}\right)$$

where C is the percent cover, M is the wood shred application rate in kg m^{-2}, and a and b are regression constants.

A one-way analysis of variance (ANOVA) was performed using a mixed model with repeated measures (Littell et al., 1996) to ensure that each replication had similar pre-treatment soil moisture and bulk density conditions. A log transformation of the soil moisture values was required to achieve normally distributed ANOVA model residuals. Least square means were determined for significant relationships using Tukey's procedure with a significance level of 0.05. A similar mixed model ANOVA analysis was performed for bulk density. A paired t-test comparing measured and desired cover was performed to determine whether the desired covers were achieved (SAS, 2002). Success in each of these three tests ensured that similar pre-treatment conditions were achieved.

A two-way ANOVA was performed to determine whether there were significant differences in runoff and soil loss due to cover or soil type. A log transform was required on the runoff and sediment data to satisfy the normality assumption of the ANOVA. The ANOVA was performed using a mixed model with soil type treated as a random variable. Runoff and soil loss were analyzed separately for each of the rainfall and concentrated flow combinations (R, $R+1$, and $R+4$). Tukey's procedure was used for making multiple pairwise comparisons. A significance level of 0.05 was selected for both the ANOVA and Tukey's procedure.

3. Results

Plot preparation methods resulted in a consistent soil water content for both soil types. The pre-treatment soil water content for the sandy loam was 6.28% (standard deviation of 2.11) and for the gravelly sand was 0.45% (standard deviation of 0.15). A one-way mixed model ANOVA for the relationship between soil moisture and soil type was performed using compound symmetric covariance structure (based on Akaike's Information Criteria (AIC)). The relationship between soil moisture and the four levels of wood shred cover was not significant.

Plot preparation methods resulted in a consistent bulk density for the sandy loam, but not for the gravelly sand. A one-way mixed model ANOVA was performed using compound symmetric covariance structure (based on AIC). The relationship between bulk density and the four levels of wood shred cover was not significant for the sandy loam. However, the first three gravelly sand plots had sufficiently lower initial bulk densities (mean 1670 kg m^{-3}, standard deviation 0.0085) compared to the remainder of the plots (average 1770 kg m^{-3}, standard deviation 0.020) to cause the ANOVA model residuals not to be normally distributed. We could find no transformation of the bulk density values that resulted in normally distributed residuals. Further, we could find no physical or procedural reason why bulk density values for the first three plots should differ. Consequently, to meet the ANOVA assumptions, we chose to remove the first three sets of rainfall simulation results performed on these gravelly sand plots from further analysis, resulting in two replications each for the 0, 30, and 70% cover on the gravelly sand soil rather than the planned three. With this design modification, the model residuals were normally distributed and results from the ANOVA showed that pre-treatment bulk density was consistent across the remaining four levels of treatment cover for the gravelly sand. All further analyses included all 12 of the sandy loam plots but only nine of the gravelly sand plots.

A paired t-test indicated that the post-adjustment wood shred coverages used in the rainfall and flow simulations were not statistically different from their desired values of 30, 50, or 70%. Treatments are referred to by their desired values.

3.1. Wood shreds application rates

Material size characteristics of the shreds are shown by both count and mass in Fig. 1. Most pieces (~90%) were less than or equal to 25 mm, less than half the smallest size determined by Foltz and Dooley (2003) to be most suitable for erosion mitigation. At the opposite extreme, 15–30% of the mass was in the larger than 200 mm size portion resulting in a material with a high number of small pieces, but with a disproportionate mass in the large sizes.

Fig. 2 displays the relationship between application rate and wood shreds percent cover. A general linear model analysis indicated that percent cover was dependent on the mass of material and the lot but not the interaction. Accordingly, there were two equations for the relationship between cover and application rate. The two equations were

$$C_1 = 128\left(1 - e^{-0.56M_1}\right)$$

$$C_2 = 177\left(1 - e^{-0.62M_2}\right)$$

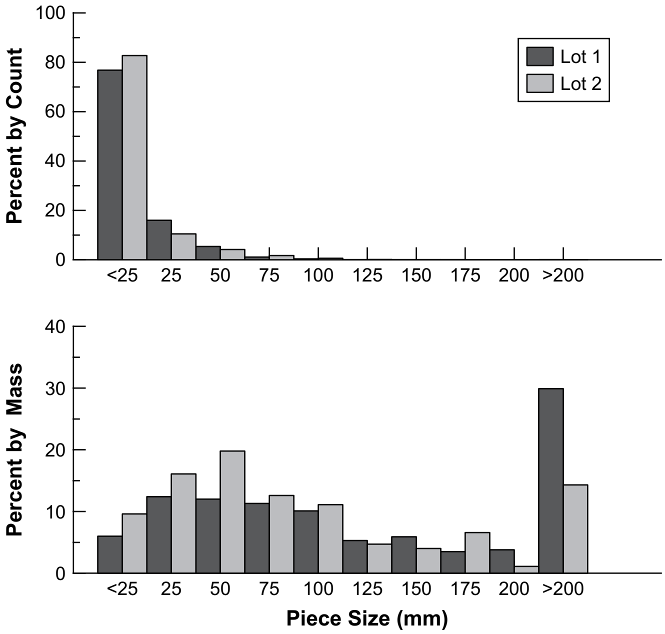

Fig. 1. Material characteristics based on percent by mass and percent by count from two lots of wood shreds. Lot 1 was used during the sandy loam soil testing and lot 2 was used during gravelly sand soil testing.

where C_1 and C_2 were the measured cover and M_1 and M_2 were the application rate in kg m^{-2} for lot 1 and lot 2, respectively.

3.2. Impact of wood shreds on runoff

Fig. 3 shows the average runoff hydrographs for each combination of coverage and soil type. Each increment of wood shreds cover increased the time to runoff. Thirty percent cover of wood shreds increased time to runoff on the sandy loam soil from 5 to 11 min with further increases of cover from 50 and 70% increasing time to 16 and 21 min, respectively. The addition of wood shred cover on the gravelly sand soil has less impact on time to runoff than on the sandy loam. Thirty percent cover increased time to runoff from 15 to 16 min with similar small increases for 50 and 70% cover.

In addition to increasing the time to runoff, wood shreds reduced the runoff rate compared to a bare plot. Reductions from 25 to 100% occurred on the sandy loam soil. Wood shreds produced reductions of 5–60% on the gravelly sand soil. For both soil types the largest reduction in runoff rate occurred during the rainfall only period (*R*).

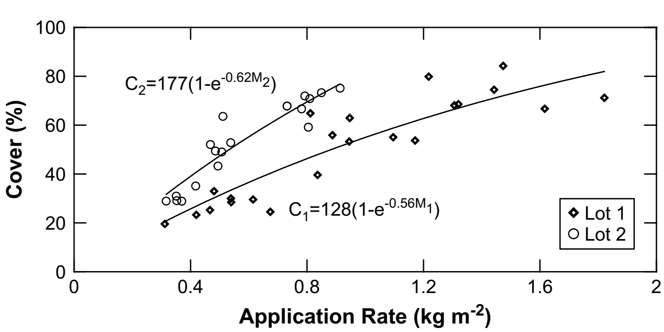

Fig. 2. Relationship between application rate and percent cover for two lots of wood shreds.

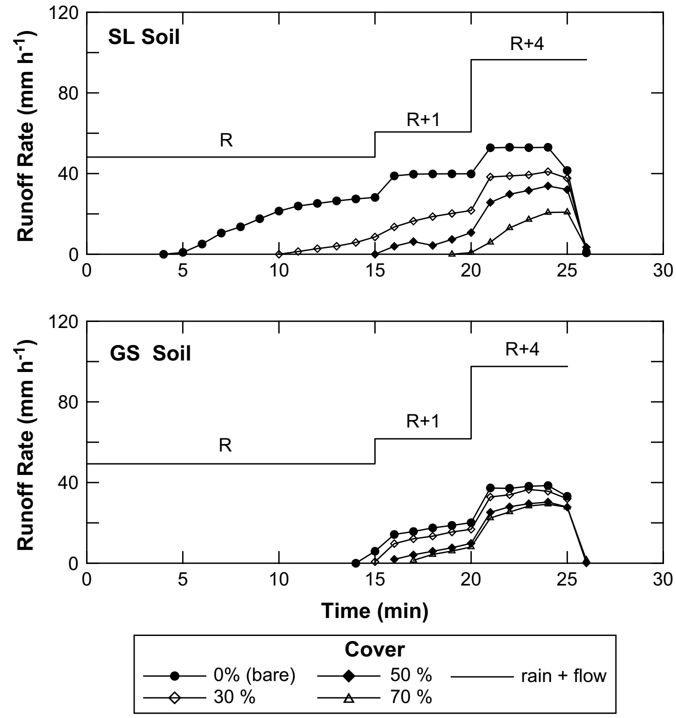

Fig. 3. Average runoff hydrographs for four coverage amounts of wood shreds on fine-grained sandy loam soil (SL) and coarse-grained gravelly sand (GS) soil.

Runoff depths for each flow period are summarized in Table 2. For the rainfall only period (*R*), 30% cover was sufficient to reduce runoff depth to essentially zero for both soils. At the other extreme (rainfall plus 4 L min^{-1} concentrated flow), wood shred cover produced a greater reduction in runoff on the sandy loam soil than on the gravelly sand soil.

3.3. Impact of wood shreds on erosion

Fig. 4 shows the average sediment delivery rates for each combination of coverage and soil type. For both soil types

Table 2
Summary of runoff depths

Soil	Cover	*R*		*R* + 1		*R* + 4	
		Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)
SL	0	3.1	46	6.3	29	10.9	20
	30	0.2	140	1.8	67	5.7	33
	50	NR	NE	0.4	110	3.4	28
	70	NR	NE	<0.01	170	1.3	22
GS	0	<0.01	120	1.3	10	4.2	4
	30	<0.01	140	0.9	56	3.7	28
	50	NR	NE	0.4	86	2.7	29
	70	NR	NE	0.2	32	2.6	6

SL – sandy loam, GS – gravelly sand, *R* – rainfall only, *R* + 1 – rainfall plus 1 L min^{-1}, *R* + 4 – rainfall plus 4 L min^{-1}, NR – no runoff, NE – no estimate.

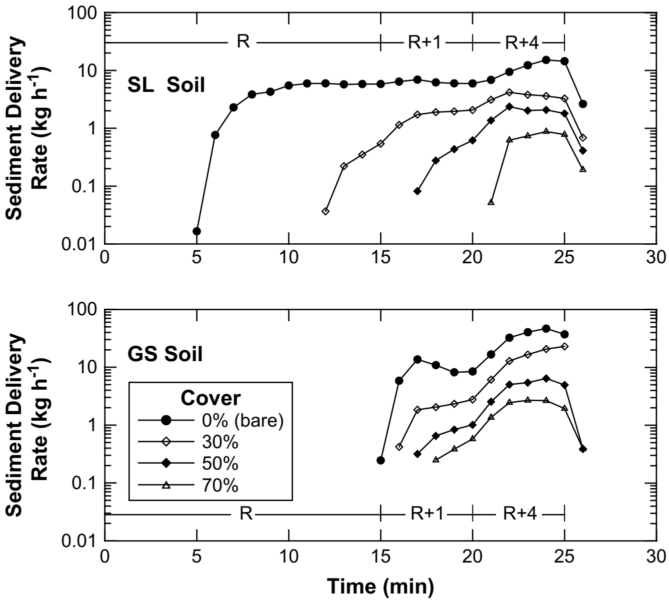

Fig. 4. Average sediment delivery rates for four coverage amounts of wood shreds on sandy loam (SL) and gravelly sand (GS) soil. Note the logarithmic scale for sediment delivery rate.

the reduction in sediment delivery rate for each flow period was greater than the reduction in runoff rate. For the sandy loam soil, wood shreds reduced the sediment delivery rate from 64 to 100% depending upon the cover and the duration and combination of rainfall and concentrated flow ($R+1$ or $R+4$). Similarly, the gravelly sand had reductions in the sediment delivery rate for each flow period from 55 to 94%. Unlike the impact on flow rate, the largest reductions were from the rainfall plus higher concentrated flow period ($R+4$).

Table 3 presents the sediment loss values for each treatment. Results of the two-way ANOVA on the log transform of the sediment loss indicated a difference between the soil types and a difference among the wood shred cover treatments at each of the three flow periods (R, $R+1$, and $R+4$). Therefore, the amount of soil loss expected from the use of wood shred cover differs depending on the soil type.

Table 3
Summary of sediment loss

Soil	Cover (%)	R		$R+1$		$R+4$	
		Mean (g)	CV (%)	Mean (g)	CV (%)	Mean (g)	CV (%)
SL	0	780	50	1310	39	2330	11
	30	20	141	170	69	480[a]	38
	50	NR	NE	20	111	190[a]	23
	70	NR	NE	<0.01	173	50	22
GS	0	4[b]	134	790[c]	2	3670[f]	4
	30	0.1[b]	141	160[c,d,e]	50	1470[f]	20
	50	NR	NE	50[d]	98	460[g]	33
	70	NR	NE	20[e]	66	210[g]	58

SL – sandy loam, GS – gravelly sand, R – rainfall only, $R+1$ – rainfall plus 1 L min^{-1}, $R+4$ – rainfall plus 4 L min^{-1}, NR – no runoff, NE – no estimate, pairwise comparisons that are NOT significant are indicated by same letter.

Tukey's procedure indicated that on the sandy loam soil essentially all pairwise comparisons of wood shred coverages were statistically significant. On the fine-grained soil each increment of wood shreds resulted in significantly less sediment loss. For the coarse-grained gravelly sand soil, Tukey's procedure indicated (1) no statistical difference between no cover and 30% cover and (2) 50% and 70% cover were always significantly less than no cover.

3.4. Impact of wood shreds on mitigating soil loss

The primary purpose of placing cover on bare soil is to mitigate soil loss where mitigation is defined as

$$M = \frac{(\text{bare} - \text{treatment})}{\text{bare}}100$$

where M is percent mitigation, 'bare' is average sediment loss of bare soil treatments (kg), and 'treatment' is average sediment loss for that treatment (kg). Application of wood shreds resulted in sediment reduction by 60–100% (Fig. 5). The largest reductions (97% and above) occurred during the rain-only period when raindrop splash erosion was reduced by the wood shreds. The amount of sediment reduction decreased as concentrated flow increased.

3.5. Impact of wood shreds on mean diameter of eroded sediments

Table 4 shows the mean diameter of the eroded sediments. Without wood shred cover, the mean diameter of the eroded sandy loam sediment was approximately the same as the soil. For all levels of wood shred cover, the mean diameter of the eroded sandy loam sediment remained similar to the mean diameter of the soil. In contrast, the eroded gravelly sand sediment without wood shred cover was finer than the soil and became increasingly finer as wood shred cover increased.

4. Discussion

Shreds were produced from random lengths and diameters of branches and small-diameter trees with a commercial wood

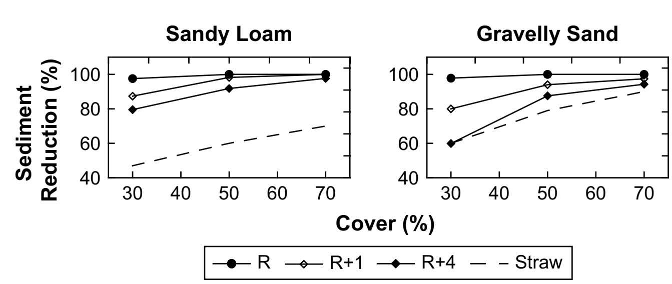

Fig. 5. Average sediment reduction compared to bare plot for three different coverage amounts of wood shreds and estimated sediment reduction for agricultural straw based on Burroughs and King (1989) for silt content and slope used in the present study.

Table 4
Mean particle size of soil and eroded sediment (mm)

Flow period	Original soil	Cover (%)			
		0	30	50	70
Sandy loam					
R	0.059	0.053	NR	NR	NR
$R+1$	0.059	0.060	0.032	0.023	NR
$R+4$	0.059	0.047	0.035	0.037	0.030
Gravelly sand					
R	0.406	NR	NR	NR	NR
$R+1$	0.406	0.294	0.230	0.171	0.142
$R+4$	0.406	0.327	0.305	0.194	0.135

R – rainfall only, $R+1$ – rainfall plus 1 L min^{-1}, $R+4$ – rainfall plus 4 L min^{-1}, NR – no runoff.

recycling grinder. Variable machine feed rates and random raw material dimensions produced the wood shreds product that resulted in the differences in size distribution shown in Fig. 1 and the need for two equations to relate application rate and percent cover. We suggest that, prior to application, each wood shreds lot be sampled to determine the relationship between mass of wood shreds and cover and that periodic recalibration of the cover versus mass relationship be performed.

The size and mass distribution of the shreds was a concern. Buchanan et al. (2000) reported that small chips were highly mobile and resulted in poor erosion mitigation. We observed that the sizes 25 mm and less did not form the three-dimensional mats that Yanosek et al. (2006) reported useful in reducing soil loss. The high proportion of sizes larger than 200 mm was also a concern because longer sizes do not have continuous ground contact on uneven surfaces and result in the formation of fewer mini-dams to trap runoff and sediment. Foltz and Dooley (2003) determined that lengths greater than 60 mm and less than 240 mm were optimum for erosion reduction and suggested a ratio of long lengths to short lengths between 2 and 2.5. The wood shreds long length to short length ratio was at least 8:1. An improved wood shred material with fewer pieces in the less than 25 mm size and less mass in the greater than 200 mm size would be desirable.

For locations where no concentrated flow would be expected (represented by R period), Table 3 and Fig. 5 suggest that 30% coverage on either soil type would be sufficient to limit erosion. In practice, achieving a consistent 30% coverage is difficult and should be attempted only under controlled conditions. Where concentrated flows are expected, represented by the $R+4$ period, 50% cover appears desirable. The additional benefit from 50 to 70% cover was smaller for the sandy loam (from 92 to 98% mitigation) than for the gravelly sand (88 to 94% mitigation). We recommend using between 50 and 70% cover of the wood shreds with the lower coverages (50%) on finer grained soils and the higher ones (70%) on coarser grained soils or where increased probability of concentrated flows exists.

Reduction in soil loss due to agricultural straw was estimated from Burroughs and King (1989) for comparison to wood shreds (Fig. 5). They developed an equation relating sediment reduction to silt content, ground slope, and straw cover from both published and USDA Forest Service in-house studies. These studies included both short-term rainfall simulations similar to the current study as well as long-term natural rainfall studies. The straw estimates in Fig. 5 were based on their equation using the soil properties and slope in the present study. Measured sediment loss from wood shreds was similar to sediment loss estimates from agricultural straw on the gravelly sand. Measured sediment reduction from wood shreds was greater than that estimated for agricultural straw on the sandy loam. Application rates of shreds to achieve 50–70% cover are comparable to those for wood strands, but 2–3 times the rate needed for agricultural straw.

What is apparent from the short-term studies by Foltz and Dooley (2003), Yanosek et al. (2006), Grismer and Hogan (2005) and the current study is that the overriding factor in erosion control is the percentage cover rather than the type of erosion control material. In the long-term (up to 5 years after application), the type of erosion control material selected becomes increasingly important. Rates of decay, susceptibility to movement by wind or water, and impacts on plant revegetation are important considerations that can only be observed in long-term field tests. The Rocky Mountain Research Station is currently evaluating the effectiveness of wood shreds, wood strands, and agricultural straw on road rehabilitation and post-fire road treatments in Idaho and Washington.

In order to be competitive with agricultural straw on large scale projects, aerial application methods need to be developed for the wood shreds. Because wood shreds are denser than straw, they will fall faster during aerial application which will require adjustments to the helicopter height and speed during application. The Missoula Technology & Development Center is currently developing an aerial delivery system. The cost effectiveness of using wood shreds and agricultural straw needs to be compared.

5. Summary and conclusions

Differences in size distribution and characteristics of the wood shreds exist due to the production process. Each lot of wood shreds needs to have the relationship between mass and cover determined prior to use and periodically thereafter.

Wood shreds were effective in reducing runoff from both the fine-grained sandy loam and the coarse-grained gravelly sand soil. The reduction was caused by the formation of miniature dams which retained runoff and sediment. Each increment of cover increased the time to runoff with the fine grain soil benefiting more. The largest reduction in runoff rate occurred during rainfall only.

Wood shreds were also effective in reducing sediment loss. On the fine-grained sandy loam soil, each additional level of wood shred coverage significantly reduced sediment loss. On the coarse-grained gravelly sand soil there was no significant reduction at 30% cover, but at 50% cover a significant sediment loss reduction was observed. There was no statistically significant reduction in sediment loss with an increase from 50 to 70% on the coarse-grained soil. Wood shreds had little impact on the mean diameter of eroded sediment from the fine-grained soil, but they reduced the mean diameter of eroded sediment from the coarse-grained soil.

Erosion mitigation due to wood shreds ranged from 60 to 100% with the largest mitigation occurring during rain only. Concentrated flow reduced mitigation effectiveness.

Wood shred cover of 50% is recommended for most applications. Mass application rates of wood shreds for coverage amounts of 50% are two times those of agricultural straw and comparable to those of wood strands.

Perhaps one of the more important conclusions from this study and similar ones is that the percentage of cover is more important than the type of erosion control material. Cost effectiveness, long-term durability, and impacts on revegetation become controlling factors in erosion control material selection.

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References

ASTM Standards, 2004. D 422-63(2002): Test Method for Particle-size Analysis of Soils. ASTM, West Conshohocken, PA.

Bower, J.L., Stockman, V.E., 2001. Agricultural residues: an exciting bio-based raw material for the global panel industry. Forest Products Journal 51 (1), 10–21.

Buchanan, J.R., Yoder, D.C., Smoot, J.L., 2000. Controlling soil erosion on construction sites with steep slopes with wood chips, ASAE Paper 002060. Presented at the 2000 ASAE Annual International Meeting, St. Joseph, MI: ASAE.

Burroughs Jr., E.R., King, J.G., 1989. Reduction of Soil Erosion on Forest Roads. General Technical Report INT-264. USDA Forest Service, Ogden, UT.

Elliot, W.J., Robichaud, P.R., 2001. Comparing erosion risks from forest operations to wildfire. In: The International Mountain Logging and 11th Pacific Northwest Skyline Symposium. University of Washington, Seattle, WA.

Fife, L., Miller, W., 1999. Rice Straw Feedstock Supply Study for Colusa County California. Rice Straw Feedstock Joint Venture, Woodland, CA.

Foltz, R.B., Dooley, J.H., 2003. Comparison of erosion reduction between wood strands and agricultural straw. Transactions of the ASAE 46 (5), 1389–1396.

Foster, G.R., Neibling, W.H., Nattermann, R.A., 1982. A programmable rainfall simulator. Paper 82-2570. In: 1982 Winter Meeting American Society of Agricultural Engineers. American Society of Agricultural Engineers, St. Joseph, MI.

Gorzell, K.E., 2001. Finding an Economic and Environmental Balance to the Technology of Producing Building Materials from Agricultural Crop Residue. Paper 01-6075. American Society of Agricultural Engineers, St. Joseph, MI.

Grace, J.M., 2002. Effectiveness of vegetation in erosion control from forest road sideslopes. Transactions of the ASAE 45 (3), 681–685.

Gregory, J.M., 1982. Soil cover prediction with various amounts and types of crop residues. Transactions of the ASAE 25 (5), 1333–1337.

Grismer, M.E., Hogan, M.P., 2005. Simulated rainfall evaluation of revegetation/mulch erosion control in the Lake Tahoe Basin – 3: soil treatment effects. Land Degradation & Development 16, 489–501.

Groenier, J., Showers, C., 2004. Shredding Small Trees to Create Mulch for Erosion Control. Engineering Tech Tips. USDA Forest Service, Technology Development Program, Missoula, MT.

Kline, R., 2000. Estimating Crop Residue Cover for Soil Erosion Control. Soil Fact Sheet No. 641.220-1. Resource Management Branch, Ministry of Agriculture and Food, Abbotsford, BC, Canada.

Kullman, G., Piacitelli, C., Parker, J., Flesch, J., May, J., 2002. Control of Organic Dusts from Bedding Choppers in Dairy Barns. NIOSH Publication No. 97-103. NIOSH, National Institute of Safety and Health, Washington, DC.

Laflen, J.M., Elliot, W.J., Simanton, J.R., Holzhey, C.S., Kohl, K.D., 1991. WEPP soil erodibility experiments for rangeland and cropland soils. Journal of Soil and Water Conservation 46 (1), 39–44.

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., 1996. SAS® System for Mixed Models. SAS Institute, Inc., Cary, N.C.

Meyer, L.D., Harmon, W.C., 1979. Multiple-intensity rainfall simulator for erosion research on row sideslopes. Transactions of the ASAE 22 (1), 100–103.

Michel, F.C., Doohan, D., 2006. Clopyralid and Other Pesticides in Compost. Extension Fact Sheet. Food, Agricultural and Biological Engineering, Ohio State University, Columbus, OH, p. 3.

National Oceanic and Atmospheric Administration (NOAA), 1973. Western U.S. Precipitation Frequency Maps. NOAA Atlas 2. Available from:. http://www.wrcc.dri.edu/pcpnfreq.html (accessed 20.09.07).

Robichaud, P.R., Beyers, J.L., Neary, D.G., 2000. Evaluating the Effectiveness of Postfire Rehabilitation Treatments. General Technical Report RMRS-GTR-63. USDA, Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 85 pp.

SAS, 2002. SAS User's Guide: Statistics. Ver. 9.1. SAS Institute, Inc., Cary, NC.

Yanosek, K.A., Foltz, R.B., Dooley, J.H., 2006. Performance assessment of wood strand erosion control materials among varying slopes, soil textures, and cover amounts. Journal of Soil and Water Conservation 61 (2), 45–51.

Yu, J., Lei, T., Shainberg, I., Mamedov, A.I., Levy, G.J., 2003. Infiltration and erosion in soils treated with dry PAM and gypsum. Soil Science Society of America Journal 67, 630–636.