Field Performance of Long-Strand Wood Erosion Control Mulch and Agricultural Straw Under Natural Rainfall Events

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Abstract

Field plots were used to compare the performance of agricultural straw mulch with a new wood-based long strand erosion control material. Two field trials were installed at locations in western Washington and central California. Slopes ranged from 15% to 25%. Soils were highly erosive loam types. Each plot was approximately 5m wide by 15 - 30m long. The studies had various start dates during the winter of 2004-2005. At all test sites, the long-strand wood erosion control mulch performed equal to agricultural straw mulch over the first six months. Decay of agricultural straw steadily reduced ground cover beginning in approximately three months, while wood-strands maintained the initial cover through the present time. One study site will be monitored through the 2005-2006 winter to assess long-term performance.

Background and Rationale

Agricultural straw is widely used for erosion control in projects throughout the world. Recent events and new knowledge challenge the advantages believed to be held by agricultural straw, particularly when used in hillslope, highway, wildland and forest applications. From an ecological perspective, erosion control mulches made from forest materials are more likely to support soil formation and health in forestlands than are mulches made from non-indigenous materials. Other limitations associated with agricultural straw erosion control materials include:

- Agricultural straw is recognized as having agronomic and ecological value when left on the field or plowed under, thus reducing the availability of straw as a crop residue (Kline 2000).
- Agricultural straw is considered a raw material for energy production, fiber panels and other potentially higher value uses, thus increasing its base cost (Fife and Miller 1999; Bower and Stockmann 2001).
- Agricultural straw has been implicated as a source of noxious weeds in forested watersheds. (Robichaud, Beyers et al. 2000; Associated General Contractors of Washington 2002).
- Fine dust from shattered agricultural straw is a respiratory irritant and source of allergens to workers who are involved in spreading straw by hand or machine (Kullman, Piacitelli et al. 2002).
- Straw decomposes rapidly, resulting in minimal effectiveness after a few months of exposure to the weather (Wishowski, Mamo et al. 1998).
- Wheat, barley and rice straw are easily blown off of slopes exposed to wind (W. Elliott, pers. Comm.). Bare areas exposed by wind are subject to increased rainfall erosion and may be trigger points for rill formation.

Preliminary research indicated that we could probably design an effective long-strand erosion control material made from wood. We further believed that we could make a product that was cost-competitive with certified weed-free straw.

Beginning in 2000, we worked to develop a manufactured wood mulch that has long strands much like agricultural straw, is easy to make and apply, and performs at least as well as straw when applied for erosion and sediment control. The core science to enable design of a long-strand wood mulch was completed in 2003 (Foltz and Dooley 2003), and optimization work continued through most of 2004 (Yanosek, Foltz et al. (in press)). This report documents the first formal field trials with what is being commercially produced as WoodStraw™ brand long-strand erosion control mulch.

Figure 1. Manufactured wood strand erosion control mulch applied at 70% soil cover.

Summary of Laboratory Results

The final round of laboratory experiments using the rainfall simulator at the USFS lab in Moscow, Idaho was completed in 2004. Variables examined in a series of factorial experiments were: strand length (160, 80, and 40mm), percent ground cover (0, 30, 50, and 70%), ground slope (15 and 30%), and soil type (decomposed granite and sandy loam). The figures below represent the effect of varying amounts of wood strand cover on runoff and sediment loss as determined from rainfall simulations. Test conditions included simulated rainfall at a rate of 50mm/hr plus two levels of added overland inflow beginning 15 minutes into the trial. A peer-reviewed report of the results is in press as of November 1, 2005 (Yanosek, Foltz et al. (in press)).

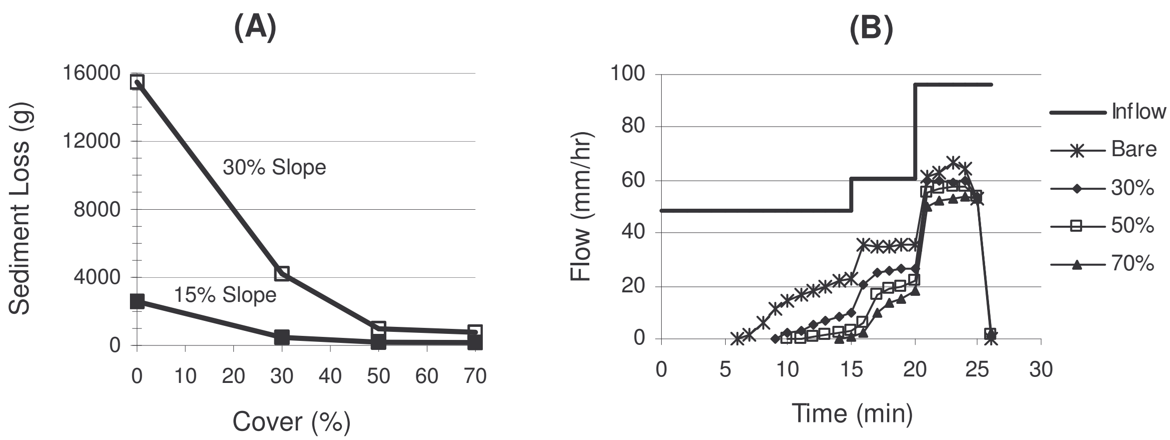


Figure 2: Sediment loss (A) and runoff hydrograph (B) for varying cover amounts of wood strands.

The USFS data shows that very effective erosion control can be obtained at 50% groundcover. This is in contrast to similar performance of wheat and rice straw at 90% cover or higher (Burroughs and King 1989). Also, the figure shows a dramatic reduction in runoff from the plots covered with wood strands. Reduced runoff due to increased infiltration captures more rainfall to support plant growth and reduces the risk of downslope flooding.

Field Research Objectives

Our primary objective for the field study program is to evaluate the functional performance of wood-strand erosion control mulch across a range of soils, slopes and climates. In addition to absolute performance, we would like to obtain comparative performance data for the wood-strand materials versus straw mulch.

Our aim is to test the hypothesis that wood-strand erosion control material is equal or better in sediment control than the standard straw mulch prescription.

We also would like to obtain observation data on the comparative performance with respect to wind stability, mobility on the slope due to overland flow, functional strand life, and rate of vegetation establishment.

Overview of Method

- Adjacent vertical strips of approximately 10 meters (30 ft) wide and 17 - 30 meters (50 - 100 ft) long were treated with agricultural straw mulch and WoodStraw™ brand wood-strand mulch at generally recommended rates. The strips were hand mulched at the specified application rate.
    - Treatments were not replicated at each site. Each of the sites included one plot of each treatment, including a bare soil plot.
    - In most cases, we did not place an upper bound on the plots. If the plots were to be of defined length, then a heavily mulched zone was installed at the top edge to catch sediment and drainage ditch was dug to divert overland flow around the plot area.
- A 5-meter (15 feet) wide silt fence sediment collector was installed at the bottom of the treated strips. The silt fence collector was similar to those specified by USDA Forest Service for evaluating hillslope erosion (Robichaud and Brown, RMRS-GTR-94, 2002). Our primary deviation was to use a short (approximately 0.4m (16 inches)) fence height to reduce the visual impact of the sediment collector.
- A recording rain gauge was installed between adjacent to the treated plots.
- After each significant rainfall event or every month, the sites were visited to collect data and observations.
- Results were analyzed and reported monthly. In this report we will use mixed units for ease of reading. Rainfall is reported in inches, while sediment is reported in kilograms.

Site Selection and Characteristics

We sought sites that included a wet and dry climate, shallow and steep slopes, and different soil types. The field trials were not intended to be a complete factorial design, rather a first indicator of field performance. If larger, more complex field trial experimental designs were indicated by the results of these trials, then appropriate sponsors and cooperators would be sought. As will be seen in the results, there are no anomalies in the results that would suggest a need for more extensive field experiments.

We recruited cooperators, and ultimately selected the Ernst Ranch in Paso Robles, CA and the University of Washington Charles Pack Research Forest as cooperators. The Ernst site is fairly steeply sloping farmland that was graded as part of a vineyard removal project. The Pack forest site is a recently graded logging road/fire break.

Additional less-formal field trials were installed in Washington at the Chambers Creek property near Tacoma managed by Pierce County, a road reconstruction project near Aberdeen, and a wetland expansion project in Federal Way. This report focuses on the formal field trails.

Figure 3: Field test site locations. Pack Forest site is near Eatonville, WA; and Ernst site is near Paso Robles, CA.

Table 1. Site Characteristics

	Pack Forest	Ernst Ranch
GPS Location	46.8411N 122.3056W	35.6413N 120.6203W
Nearest Town	Eatonville, WA	Paso Robles, CA
Date Installed	March 31, 2005	Dec. 4, 2004
Slope	20-25 %	16 – 19%
Soil Type	Wilkeson fine loam	Arbuckle fine sandy loam over decomposed granite
Aspect	Southwest	South
Elevation	1500 ft	900 ft.
Climate	Puget Sound Maritime	Semi-arid (< 10 in. / year)

Plot Installation

Ernst Site: The farmland site had been tilled and graded during 2004 when a vineyard was removed from the property. Immediately prior to installing the plots, the site was re-graded with a tractor/scraper to remove all vegetation, smooth the surface, and bring fresh topsoil to the surface. The study area was large enough to include three test areas – wood-strands, bare soil, and straw mulch. The remainder of the field below the plots was previously planted with pasture grass, thus providing a buffer for excess sediment that may be released by the bare soil plot.

Silt fence sediment collectors were installed and the corners of each plot were marked with pin flags. Photo points were established, slopes were measured and the rain gauge was installed. Erosion control barley straw was from bales made by the Ernst Ranch cooperator from stubble produced on another part of their property. Forest Concepts provided WoodStrawTM wood-strand mulch. The product designator is LS64-125. The material included a 50:50 by area blend of strands that were 160mm and 64mm long. Material thickness was 3.2mm (1/8 in) and strand width was 4.7mm (3/16 in).

All materials were hand-spread to a target ground cover. The barley straw mulch was applied to a target cover of 90%, and the WoodStraw^{TM} mulch was applied to a target cover of 70%. These application rates are consistent with generally accepted practice for straw mulch, and the laboratory-based optimum for WoodStraw^{TM} mulch on highly erosive granitic soils.

The test plots were sprayed with a broad-spectrum herbicide (Roundup) one week after the plots were installed, and monthly since that time. Herbicide applications ensure that the results are not confounded by the development of vegetative cover and root mass.

Pack Forest site: The forestland site is a recently logged area of the University of Washington's research forest. A combination skid trail and fire break had been graded straight down a 20-25% slope. The graded area was approximately 4m wide and 100m long. Plots were marked along the trail from top to bottom. Each plot was approximately 17m (50 ft) long. A silt fence sediment collector of the same design used at other sites spanned the bottom of each plot. A 2m (6 ft) zone below each silt fence and above the next plot was mulched with wood strand material at a 90 percent surface cover. This buffer mulch was intended to disperse water that might flow through from plots above, and encourage infiltration of the downslope water.

Plots were randomly assigned to treatments, with the upper plot being wood-strands at 50% cover, then bare soil control, wheat straw at 90% cover and finally wood-strands at 70% cover at the base of the slope. Hand crews applied all mulch treatments.

Ernst Site Results

The experiment was installed on December 6, 2004 and the landowner/cooperator will continue to monitor the site through 2005. The site was dry until approximately December 27, when a series of major storms moved across southern California. Figure 4 shows the cumulative rainfall for the study period. In addition to cumulative rainfall, we were able to calculate instantaneous intensity for each tip of the rain gauge (0.01 in). Rainfall intensity is well understood to be a more important driver of soil erosion than cumulative rainfall. As long as the intensity is below the rate of infiltration, no runoff will occur. When intensity exceeds infiltration, then the amount of runoff is a function the excess rainfall.

The intensity graph in Figure 6 shows that the site was subject to five short duration events where the intensity exceeded one inch per hour. There were approximately sixteen events where the rainfall intensity exceeded the landowner's one-half inch per hour estimate of soil infiltration rate.

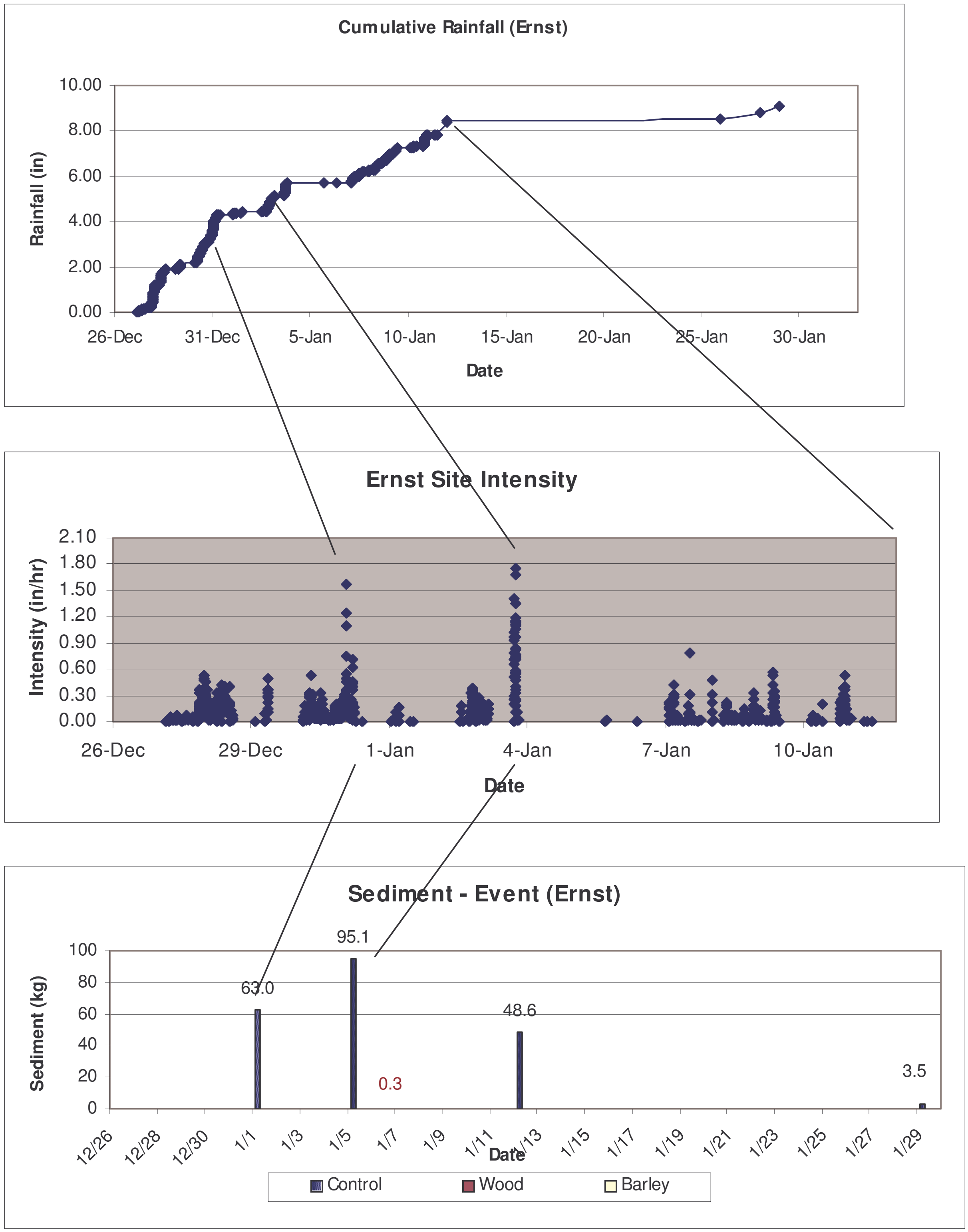


Figure 4. Linked graphs from Ernst site for the period December 26, 2004 through January 30, 2005.

The first series of storms that occurred after installing the plots clearly shows the relationship between rain intensity and erosion rate. The landowner collected sediment at the first day after each storm when he could get to the site. The first rain event on December 28-29 had a peak intensity of approximately 0.6 in/hr and did not produce runoff from any of the plots. However, the December 30-31 event with peak intensity of over 1.5 in/hr produced runoff from the bare soil plot. A total of 63kg (139 lb) (dry weight) of sediment was removed from the bare soil plot and none was recovered from the straw or wood-strand plots.

A larger rainfall event on January 3-4 resulted in 95kg (209 lb) of additional sediment from the bare soil plot, 0.3 kg (10 ounces) of sediment from the wood-strand plot and still no sediment from the straw plot. As can be seen from the figure, additional runoff and sediment occurred on the bare soil plot at each major event, but no additional sediment was delivered from either the straw or wood-strand plots.

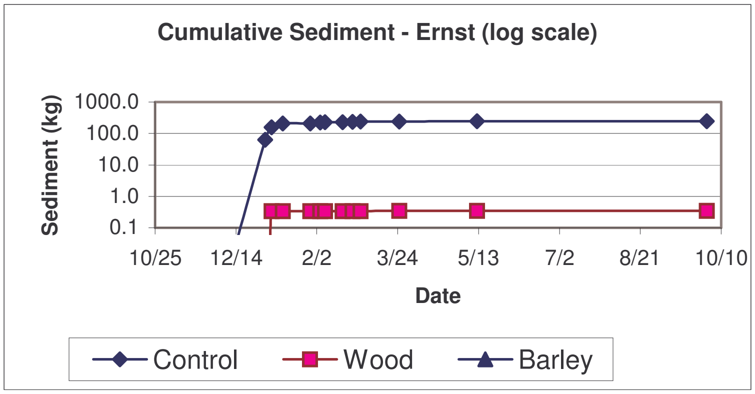


Figure 5. Cumulative sediment for treatments at Ernst site.

After a number of large storms in January 2005, the remaining winter rains were relatively light. The graph above shows the cumulative sediment over the winter 2004/2005 field trials at the Ernst site. As of March 31, the cumulative amount for bare soil plot was 243kg; the wood-strand plot was 0.3kg and 0.0kg for barley straw plot. No rainfall occurred from March 31, 2005 through October 31, 2005. The graph is presented on a log scale since the treated plots produced less than one-percent of the sediment that was captured from the bare soil control plot.

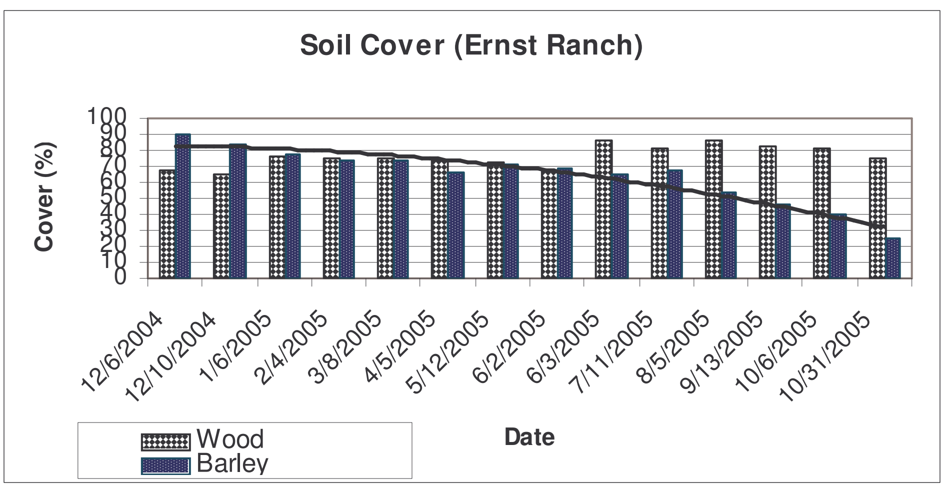


Figure 6. Measured soil cover for wood-strand mulch and barley straw mulch.

As noted earlier, the target application rate for barley straw was 90 percent and for wood-strands was 70 percent. Measurements of mulch coverage were taken monthly using a point-intercept grid on a clear acrylic sheet. The square grid had 64 points spaced 40 mm apart. The grid was placed at a minimum of eight semi-random locations on the upper, middle, and lower sections of the plot. Points directly above functional mulch pieces were considered "hits." Total hits as a percentage of total points were used to determine the percent cover.

Over the eleven months from December 6, 2005 through the most recent observations, the wood-strand cover continued to be at the applied rate with no apparent loss of ground cover. Variation from observation-to-observation is visible in Figure 6; however, the cover differences are not significant. The cover for barley straw has declined from an initial 90 percent in December 2004 to a November 2005 cover of approximately 25 percent. By observation, the initial reduction in straw cover was due to loss of leaf area as the leafy components decayed. The current straw mulch cover is primarily associated with fragments of stalk material.

We can suggest a decay equation for the barley straw plot based on 13 observations to-date. The regression equation for soil cover in the barley straw plot is

$$\text{Cover} = -0.2658t^2 + 0.0513t + 83.258 \qquad \text{(equation 1)}$$

$$\text{Cover Remaining} = -0.004t^2 - 0.0073t + 0.9139 \qquad \text{(equation 2)}$$

Where

Cover -- percent of the soil surface covered by functional material

Cover Remaining – normalized cover as a percentage of the initial soil cover

t -- time since application in months

The R^2 of this equation on our data is 0.91

The Ernst site near Paso Robles, California received nearly 12 inches of rainfall during the 2004-2005 winter season. Rainfall included approximately sixteen events where the intensity exceeded infiltration, and six events where the intensity exceeded 1.5 inches per hour. More than 230 kg of sediment eroded from the bare soil control plot, while only 0.3 kg eroded from the wood-strand plot and none eroded from the straw mulch plot. In agronomic terms, the bare plot eroded at a rate of 7.3 tons per acre.

Both erosion control materials performed flawlessly during the first three months, and reduced sediment by more than 99 percent compared to the bare soil plot. During the first three months after application, there was no difference in performance between wood-strand mulch and barley straw mulch when applied at the tested rates of 70 percent cover for the wood-strands and 90 percent cover for the barley straw.

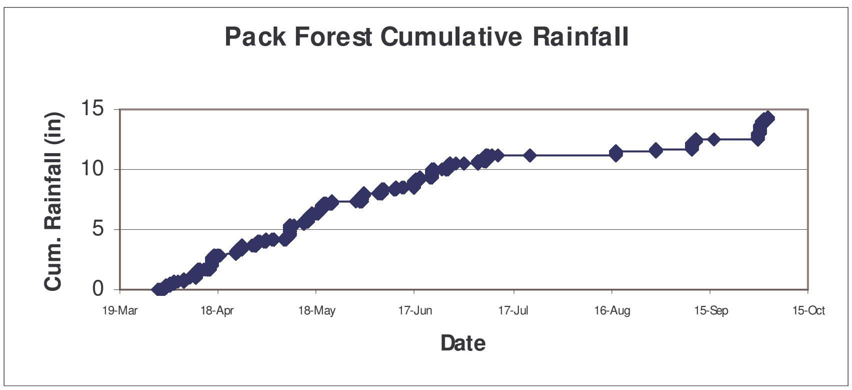
Figure 7: Ernst site on January 3, 2005 with wood-strand plot on the left, bare soil in the center, and barley straw plot on the right. As of this date, neither of the treated plots showed any signs of rill erosion while the bare soil plot is heavily eroded.

During the dry summer months, the barley straw cover decayed to a current (November 1, 2005) cover of less than 25 percent, with many large bare patches. The wood-strand cover has neither decayed nor moved, thus the current cover is statistically equal to the initial cover. We expect the wood-strand plot to continue to control erosion through the second winter, while the barley straw plot should have little effect.

Pack Forest Results

The Pack Forest trial was installed on March 31, 2005, thus missed the winter rain season. The experimental design enabled us to test two soil cover rates for the wood-strand material. Most erosion control best management practice prescriptions (BMP) strive for at least 90 percent sediment reduction. If the wood-strand treatment could achieve at least 90% sediment reduction, then contractors and land managers could potentially save money and labor by applying wood strands at a relatively low rate. We expected that the 70% soil cover rate would control sediment at 98-99 percent reduction. We wanted to determine if 50% soil cover would reduce sediment by at least 90 percent as we had observed in the laboratory research.

The research forest experienced a very typical spring and summer rain pattern with almost daily rain from the beginning of the study through June, then periodic summer storms. The site was subject to nine events where the peak rainfall intensity exceeded one inch per hour, and two events where the peak intensity exceeded four inches per hour, albeit for a very short time. Since sediment data was collected monthly, we do not have separate data for individual large events at this site.



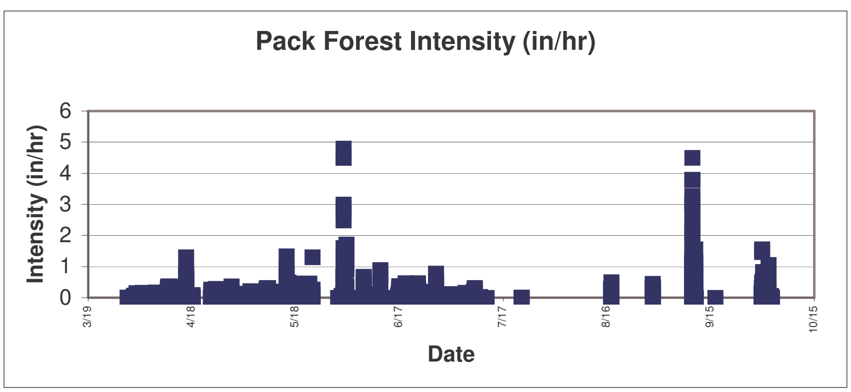


Figure 8. Cumulative rainfall and intensity data for the Pack Forest site from March 31 through October 6, 2005.

Sediment production from the plots has been very similar to our results from the laboratory rainfall simulator studies. Agricultural straw applied at 90% soil cover (BMP rate) resulted in 98 - 99 percent reduction in sediment during the first six months after application. Wood-strand mulch applied at an initial cover of 75% (inadvertently somewhat higher than our target) also resulted in 98 - 99 percent reduction in sediment during the first six months after application. The low-rate wood-strand plot was initially applied at a rate of 50 percent, and has resulted in a 95 percent reduction in sediment during the first six months after application. These results are exactly in line with our laboratory results (Foltz and Dooley 2003; Yanosek, Foltz et al. (in press)).

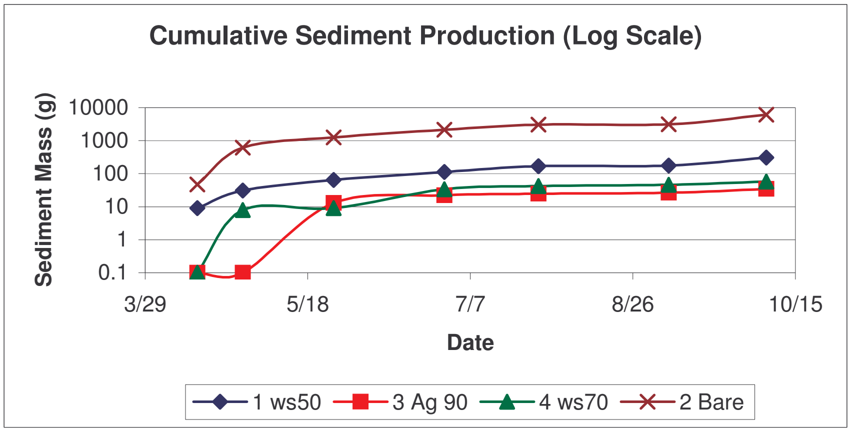


Figure 9. Cumulative sediment production from Pack Forest treatments.

Loss of soil cover through material decay, wind or other factors is also progressing as expected at the Pack Forest site. Neither of the wood-strand treatments has varied significantly from the initial application rate. The agricultural straw cover is trending downward on an almost identical curve to that observed at the Ernst Ranch site, even though the climates are considerably different. Over six months, the straw cover has reduced from an initial 90 percent to a current 60 percent, still enough to provide effective erosion control. However, we expect the loss of cover to accelerate during the next six months. We are not yet able to derive a decay curve for any of the Pack Forest treatments.

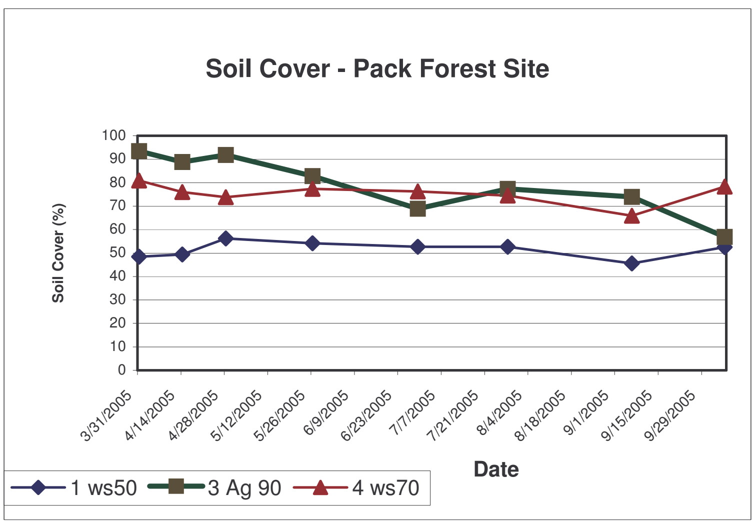


Figure 10. Soil cover for erosion control treatments on the Pack Forest field trial site.

Conclusions Across Sites

Our field tests sought to achieve two objectives. The first was to determine the amount of sediment reduction for wood-strand material as compared to agricultural straw when both were applied at recommended rates. The second was to assess the performance life of wood-strand material as compared to agricultural straw.

We can evaluate the degree of sediment reduction for each observed time period, and the cumulative reduction through the duration of each field study. Summary tables below show the data for the Ernst and Pack Forest field study sites.

Table 2 Ernst Site sediment reduction results for agricultural straw (AG), wood-strands (WS) and bare soil control (Bare) plots.

Percent Reduction Ernst Site							
	This Time Period Sediment Reduction (%)				Cumulative Reduction (%)		
Plot / Date	Ag 90	ws70	Bare		Ag 90	ws70	Bare
12/6/2004	100	100	0		100	100	0
1/1/2005	100	100	0		100	100	0
1/5/2005	100	99.6	0		100	99.8	0
1/12/2005	100	100	0		100	99.8	0
1/29/2005	100	100	0		100	99.8	0
2/4/2005	100	100	0		100	99.8	0
2/7/2005	100	100	0		100	99.9	0
2/18/2005	100	100	0		100	99.9	0
2/24/2005	100	100	0		100	99.9	0
3/1/2005	100	100	0		100	99.9	0
3/25/2005	100	100	0		100	99.9	0

Table 3. Pack Forest Site sediment reduction results for agricultural straw (AG), wood-strands at 50% cover (WS50), wood-strands at 70% cover (WS70) and bare soil control (Bare) plots.

Percent Reduction Pack Forest Site									
	This Time Period Sediment Reduction (%)					Cumulative Reduction (%)			
Plot / Date	ws50	Ag 90	ws70	Bare		ws50	Ag 90	ws70	Bare
4/14/2005	80.9	100.0	100.0	0		81	100	100	0
4/28/2005	96.1	100.0	98.6	0		95	100	99	0
5/26/2005	94.9	98.0	99.8	0		95	99	99	0
6/29/2005	94.4	99.0	97.2	0		95	99	98	0
7/28/2005	94.0	99.7	99.1	0		95	99	99	0
9/6/2005	79.2	94.2	88.8	0		94	99	98	0
10/6/2005	95.6	99.7	99.6	0		95	99	99	0

We conclude that our hypothesis is true where we tested whether wood-strand mulch applied at approximately 70% soil cover was functionally equivalent when compared to agricultural straw applied at the BMP rate of 90% soil cover.

We conclude that wood-strand mulch of the type used in these field trials did not decay nor otherwise lose its soil cover performance during the field study period of 11 months in California and six months in western Washington.

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NOTE: Yanosek paper title and publication date will change to match actual publication

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