forestconcepts™ **Summary Report**

DEVELOPMENT AND APPLICATION OF WOOD-STRAND MATERIAL FOR POST-WILDFIRE EROSION CONTROL AND REVEGETATION

James H. Dooley[1], Michael C. Perry

Updated: April 30, 2015

Abstract. Soil erosion is a significant risk on burned areas following wildfires due to loss of vegetation, fine surface debris, and fireline construction. Erosion may be triggered by wind, resulting in loss of topsoil and ash with resulting air quality effects, or by rainfall that displaces seeds, creates rills, and washes topsoil downslope. A range of materials are commercially available to reduce the erosive effects of wind and/or rainfall, including agricultural straw, hydraulic mulches, shredded woody debris (slash), and rolled erosion blankets. Each of the conventional materials have limitations and operational issues that led federal agencies to support development of a new all-wood strand material beginning in 2002. They sought a new wood-based erosion control material that would be long-lasting, wind resistant, naturally weed-free, and could be transported and applied using conventional hay and straw methods. Three years of joint research and development between the USFS Rocky Mountain Research Station and Forest Concepts resulted in a wood-strand material that is optimized for technical performance, baling for storage and transport, and ease of application. The wood-strand material is now sold under trade names WoodStraw® and Blue-Straw™. More than 15,000 tons of the wood-strand material has been used on a range of road, post-wildfire, mine reclamation sites, watershed protection, streambank, ski area, recreation trail, utility corridor, and other uses across federal, state, and private lands in the western United States.

This paper:

- Reviews the science and design process that led to the technical features of the wood-strand mulch,
- Discusses field performance on a range of sites across the western United States.

[1] James H. Dooley, PhD, P.E., is Chief Technology Officer of Forest Concepts, LLC, Auburn, WA 98001, and Michael C. Perry is CEO of Forest Concepts, LLC. Website: www.woodstraw.com

Section 1. Introduction

Agricultural straw is widely used for erosion control in projects throughout the world, including highway construction, commercial and residential development, road and trail decommissioning, post-wildfire rehabilitation, and other places with disturbed landscapes. Straw is inexpensive, readily available and easy to spread by hand or machine. Recent events and new knowledge challenge the advantages believed to be held by agricultural straw, particularly when used in hillslope, mine, pipeline, highway, wildland and forest applications. Limitations associated with agricultural straw erosion control materials include:

- Agricultural straw has been implicated as a source of noxious and "farm" weeds not already naturalized in a landscape (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 weeks or months of exposure to the weather (Wishowski, Mamo et al. 1998).
- During the critical first weeks after seeding and mulching, straw mats may absorb and trap most of short-duration rainfall events that re-evaporate to the air, thus reducing rainfall infiltration to support germination and early seedling growth (R. Foltz, Per Comm.)
- Wheat, barley and rice straw are easily blown off of sites exposed to wind (Copeland, Sharratt et al. 2006; Copeland 2007; Copeland, Sharratt et al. 2009). Bare areas exposed by wind are subject to increased erosion and may be trigger points for rill formation and for sediment movement. Straw is documented to blow away at less than 6 m/s (13 mph) (Whicker, Pinder et al. 2002).
- Straw from fields and portions of fields treated with the broadleaf herbicides clopyralid and picloram compounds are known to carry those materials to sites where the straw is used as mulch and either prevent broadleaf seeds from germinating or result in distorted plants (de la Fuente 2002; Dow AgroSciences 2002). The manufacturer's herbicide labels specifically recommends against using straw from treated fields as mulch when broadleaf plants are present or included in reseeding mixes.
- 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).

Forest Concepts was first approached in 1998 by a regional manager from the Washington State Department of Ecology and was asked to develop a wood-based alternative to agricultural straw mulch for use in the Seattle watershed. The department's objective was to reduce invasive weeds and herbicide residue leachates that were documented from use of wheat straw on road obliteration projects. A similar request was received from USDA Forest Service and USDI Bureau of Land Management erosion control specialists in 2001 as they faced uncontrollable invasive weed infestations after use of agricultural straw on road and post-wildfire projects in the Bitterroot valley of Montana.

All three of these land management agencies wanted a material that was:

- Environmentally compatible with forest soils and ecosystems where it was being applied, both during its functional life and as it decayed into duff or soil organic matter,
- Long-lasting with sufficient functional stability and performance life until seeded or natural revegetation provides at least 50 % soil cover and assume the natural roles of rainfall interception and surface water erosion control,
- Inherently weed-free without need for sterilization, chemical treatment, or inspection,
- Baled and able to be applied with straw blowers and helimulch operations so as to use proven and existing baled-straw logistics, helimulch, and straw blower application systems,
- Effective in high winds (defined by the USFS as 35 miles per hour at the surface), and
- Effective on slopes from flat surfaces to at least 30% slope on highly erosive soils.

The engineering team at Forest Concepts was selected by USDA in 2002 to develop a new wood-based erosion control alternative to agricultural straw for use on public lands. Forest Concepts was known to have deep competencies in:

- translating natural resources issues into engineering functional objectives (Dooley 1994; Dooley 2000),
- a development process that leads to innovative and effective solutions (Dooley and Fridley 1996; Dooley and Fridley 1998), and
- experience designing new wood products and processing methods (Dooley and Fridley 1998; Dooley and Paulson 1998).

The USDA Small Business Innovative Research Program (Contract numbers 2002-33610-11874, 2003-33610-13997) provided funding for Forest Concepts to work with the Forest Service and other specialists to design a wood-strand material that looks, applies, and performs like straw, BUT is naturally weed-free and ecologically compatible with forest soils. Additional programmatic funding was provided by the US Forest Service Washington Office (WO) to the USDA Forest Service Rocky Mountain Research Station Moscow Lab to support the Forest Concepts effort.

Section 2. Problem Analysis

Engineers, together with technical and market specialists began the development effort by conducting a thorough technical problem analysis, understanding the literature surrounding erosion control, and translating natural language needs expressed by land managers into actionable design and performance specifications.

Rainfall Erosion Problem

Soil erosion from disturbed areas and low-volume roads is a major source of water pollution in all areas of the United States (Dunne and Leopold 1978). Water-related erosion is the movement of soil downslope due either to the splash of raindrops or overland flow of water. For unprotected soils associated with wildfires and construction/grading activities, the accelerated rate of soil erosion can produce negative effects downslope. Sediment that enters streams from upslope erosion is associated with the decline of salmonids in the Pacific Northwest (Bisson, Reeves et al. 1997). Federal, state, and local water quality regulations prohibit discharge of sediments from construction activities into lakes, streams and rivers. Regulations also require contractors and agencies to use approved erosion prevention and sediment control methods. Soil erosion potential and sedimentation risks are also major elements of post-wildfire assessments and emergency response (aka BAER) programs.

The causal mechanisms for rainfall-induced erosion include raindrop impact that dislodges soil particles and overland flow of water acting upon an unprotected or erosive soil. The rate of erosion is a function of soil type, slope, rainfall intensity and duration, soil cover, root strength and many other factors. For a given climate and site condition, the primary method of controlling the erosion rate on disturbed land is to manipulate soil cover through the addition of mulches, blankets, and the like. It is expected that vegetation will establish and grow to assume the cover function over time.

Soil particle mobilization through raindrop impact has been studied extensively in the past (e.g., (Ellison 1944; Thompson and James 1985). The only effective method found to reduce raindrop impact is to provide soil cover with a material that absorbs the force of raindrops and protects soil aggregates from direct impact from raindrops. This "complete coverage" desire is in conflict with desires to maximize delivery of rainfall to arid soils and maximize infiltration while not impeding germination and emergence of new broadleaf and grass vegetation.

Design of an optimal wood-strand erosion control material seeks to achieve the dual functions of intercepting rainfall drops and increasing on-slope storage of water and sediment. Increasing soil cover should decrease the rate of raindrop induced mobilization of sediment. Increasing the surface roughness through higher soil contact and material piece count should decrease water velocity and increase depression storage. That is, ponding of overland flow above a wood strand reduces the velocity and provides an increased opportunity for infiltration. As predicted by the Random Roughness relationships for depression storage, the effect to reduce erosion and increase infiltration can be significant (Govers, Takken et al. 2000). With an engineered wood strand, we expect that the roughness effect will last for several growing seasons. This contrasts to the roughness effect of straw, which is generally lost within a few weeks to months (Wishowski, Mamo et al. 1998).

Rainfall Absorption and Re-evaporation Problem

A portion of the leading edge of rainfall events is captured by erosion control mulch through a combination of matrix surface tension, adsorption, and absorption. This is an un-quantified side effect of using organic mulch for erosion control. In the case of thick mulches such as agricultural straw or absorptive fibrous mulches such as hydraulic mulch and those including polyacrylamide additives, capture of rainfall from short duration, low intensity events may effectively preclude soil infiltration of rainfall needed for soil organisms, seed germination, and plant growth. However, capture of the leading edge of short duration high intensity events (e.g., thunderstorms) may also preclude soil erosion, rill formation, and downslope flash floods. Tradeoffs between concurrent objectives of erosion control and maximizing infiltration require that managers have access to data on rainfall capture by alternative mulch materials.

Since no data existed in the literature, Forest Concepts conducted a rainfall simulator experiment to quantify rainfall interception and storage by straw mulch applied at BMP (best management practices) rates and an early version of the wood-strand mulch being developed for federal agencies. Both materials were evaluated in small plots on a sloped-table rainfall simulator. Simulated rainfall was applied for up to 25 minutes at 54 mm/hr with large droplets typical of summer rains in the interior Northwest. Over the entire 25-minute event, the wheat straw captured 3.5 times the rainfall (2782 g/kg vs. 796 g/kg) that was captured by the wood-strand material when both were applied at a rate of 4.5 Mg/ha. In just the first three minutes of a simulated high intensity event, the wheat straw captured 2.9 times the rainfall (2131 g/kg vs. 734 g/kg) versus the wood strand material. When the results were allocated to a treatment area basis, the wheat straw mulch at an application rate of 4.5 Mg/ha should capture approximately 1 mm of rainfall in the first five minutes of a high intensity event and approximately 1.25 mm over the first 25 minutes. In contrast, the wood strands captured 0.33 mm in the first five minutes and little more over the remaining time periods.

We concluded that both wheat straw mulch and wood-strand mulch capture most of their potential water holding capacity in a very short time after the onset of high intensity rainfall. We also concluded that large differences exist in the amount of rainfall captured by wheat straw and wood strands. Therefore, if the primary management objective is to increase rainfall infiltration opportunity while achieving good erosion control, then the wood-strand material will be a preferred option.

Wind Erosion Problem

Wind erosion is a major ecological, social, and human health problem, with only limited means for its control. Wind erosion on burned areas, construction sites, low volume roads, and bare-soil is a substantial source of particulate pollution and public outcry. Loss of soil from disturbed sites due to wind erosion affects the health and quality of life in downwind neighborhoods and communities. Untreated mine tailings and mine site reclamation projects are also substantial sources of dust until such time as surface organic matter and vegetation develop to provide soil cover (McGinley 2002). Additionally, large areas of forest and grasslands adjacent to neighborhoods and communities are burnt each year in wildfires. Post-wildfire wind erosion includes ash, cinders, and burnt mineral soil.

One recent study (Whicker, Pinder et al. 2002) on the Los Alamos National Laboratory site concluded that wind erosion rates were significant at wind velocities above 6 m/s (13 mph). In this instance, suspension and re-suspension of nuclear contaminants after wildfire was a specific wind erosion control concern for Los Alamos. Field studies conducted near Lubbock, Texas by Stout (Stout 2004) to validate a method for establishing the critical threshold for aeolian transport of soil also found that wind velocities in the range of 6 m/s resulted in the initiation of wind transport of soil particles. In the Columbia Basin of Washington State, wind velocities of 6 m/s have a two-day occurrence interval (Copeland, Sharratt et al. 2006).

There are many chemical wind-erosion and dust-control products on the market, but few that can be used on areas slated for revegetation. Dust control products (aka dust palliatives) fall into a number of types (Hare 2007):

- Deliquescent salts - Calcium chloride
- Lignosulfites - Lignite sulfide, pulp mill black liquor
- Resinous products
- Petroleum emulsions – Asphalt emulsions
- Polymers – Acrylic co-polymer, Polyvinyl acetate, and similar adhesives
- Hydraulic short-fiber mulch – Wood-fiber mulch, bonded fiber matrix
- Water – Delivered by water trucks or sprinklers

Erosion control chemical sprays can prevent revegetation or produce ongoing soil problems (Raskin, DePaoli et al. 2005). Of the available materials, only hydraulic mulch and water are recommended for sites that will ever be revegetated. Water is only effective for a few hours at best, and its use is discouraged in areas where water-use restrictions are in effect. Thus, contractors in urban and suburban settings seek effective materials for those portions of their sites that are not amenable to chemical dust palliatives. Hydraulic mulch has a functional life of a few weeks or months, unless seed is added and irrigation or natural rainfall is sufficient to grow vegetative cover. Hydraulic mulch cannot be driven over at any time or the fragile matrix will tear and easily blow off of the treated area. Further, contractors working in forests and natural areas are typically unable to draw water from streams, ponds and rivers due to environmental protection and fisheries regulations.

A new wind erosion control material was needed that: a) does not require mixing with water, b) is wind-stable on open graded or burned areas, c) is compatible with future revegetation, d) can be applied over bare soil around trees, and around perennial vegetation, and e) is effective at reducing both rainfall soil erosion and dust emissions from bare soil.

Herbicide Carryover Problem

The problem of herbicide carryover from agricultural crop management to straw-mulched sites is an ongoing issue and topic of discussion. Occasional revegetation failures on public lands mulched with wheat and barley straw could not be explained by lack of rainfall, poor seed viability, or other plausible factors. Questions have been raised as to whether revegetation issues, particularly those where grasses emerge well and broadleaf plants are suppressed or missing could be caused by herbicide carryover in agricultural straw mulches. Although issues with herbicide carryover from grain crops to sites mulched with straw have been well documented for urban gardens and organic farms, formal studies of herbicide issues on public land erosion control products had not been conducted. We have been unable to find any peer reviewed or general literature studies of how herbicide residues in erosion control straw products and revegetation straw mulch affect broadleaf species abundance and richness on construction sites or disturbed land. This is not surprising in one sense because such use of baled residue from herbicide treated crops is prohibited by the herbicide label (Dow AgroSciences 2008) and neither mulch buyers or sellers are likely to admit to using an unpermitted material. However, anecdotal reports suggest that baled straw mulch from herbicide treated fields is widely available on the commercial market.

The herbicide clopyralid has been registered for use in the United States since 1987 (Cox 1998). The chemical is used alone or in combination with other herbicides (Dow AgroSciences 2002) on wheat, barley and other grain crops. Clopyralid and the related picloram compound are synthetic plant hormones that have been proven to be particularly effective to provide long-term control of broadleaf weeds in grain crops. Clopyralid containing products were first registered in California in 1997 (de la Fuente 2002) and across the western US at about the same time. Immediately thereafter, reports began to emerge about apparent herbicide damage in gardens and crops where straw-based and lawn-grass composts and mulches had been applied (Granatstein 2001; de la Fuente 2002; Washington State University and Washington State Dept. of Ecology 2002; Gaolach). As a result, the use of clopyralid and picloram in residential consumer weed killers was stopped, while agricultural use continued.

Both of these materials, clopyralid and picloram, are reported by the manufacturer, Dow AgroSciences, to bio-accumulate in the stalks of grain crops and affect the germination and growth of non-grass species when the straw is used as a mulch (Dow AgroSciences 2002; Dow AgroSciences 2007; Dow AgroSciences 2008). The labels for both herbicides specifically warn: *"Do not use straw from treated crops for composting or mulching on susceptible broadleaf crops."*

Unfortunately, in spite of label warnings, crop residue from herbicide treated fields is reported to be routinely baled and sold for erosion control mulch. Such use may be inadvertently encouraged by University Extension publications that recommend spraying of hay and grain fields destined for "certified weed-free feed" with clopyralid and similar herbicides (de la Fuente 2002). At this time, there are neither state nor federal requirements to test for clopyralid residues in straw, compost, or mulches; however, increasing numbers of buyers (e.g. Woodland Park Zoo) are requiring testing as part of their supply contracts. As a result, herbicide containing straw may be unknowingly used in straw erosion control blankets, straw-based hydraulic mulches, and in baled straw erosion control and revegetation materials. Note that we are using the term “herbicide containing straw” rather than “herbicide contaminated straw” since the presence of the herbicide is a result of planned cultural practices and not accidental or unintentional.

One of the earliest operational uses of the then-new wood-strand erosion control mulch was by the USDI BLM Boise District on the Snake One fire (B19E) near Weiser, ID in the fall of 2005. BLM technical specialist Cindy Fritz monitored the application of seed, straw, and wood-strands during the initial application and for the following three seasons. Aerial seeding was prescribed on 5,790 ha (14,300 acres) and included a grass/forbs mixture. Drainage areas with high erosion potential were helimulched either with agricultural straw or WoodStraw® wood-strand mulch. Her *Third-Year Closeout ESR Monitoring Report* (Fritz 2008) reported that overall revegetation success was high in the mulched areas and marginal where seeding was not followed by mulching. Total vegetative cover in years one, two, and three was higher in the wood-strand treated areas than in the agricultural straw treated areas. The plant community in both treatments was about evenly divided between native grass, perennial forbs, and seeded annual grass. Shrub species were only apparent in the wood-strand plots and not present in the straw mulched plots. One potential explanation for the increase of shrub species in the wood-strand mulched areas could be related to persistent herbicide residues in wheat straw used on the project. Unfortunately, there was no way for the BLM staff to trace the straw back to the grower or farming practices, so the herbicide connection was speculative.

Section 3. Development and Testing of Wood-Strand Erosion Control Material (aka WoodStraw® ECM)

The 2002-2003 USDA SBIR Phase I activities included disciplined engineering design and experimentation to specify physical properties for a wood-strand straw analog that meets or exceeds the performance of certified agricultural straw. More than 35 experimental runs were completed on the Forest Concepts rainfall simulator in Federal Way, Washington. Research quantities of wood-based strands of designated lengths and widths were produced for laboratory testing by the U.S. Forest Service Rocky Mountain Research Station (RMRS). Twelve additional experimental rainfall simulator runs were completed by Dr. Randy Foltz in a carefully designed experiment at the Rocky Mountain Research Station in Moscow, Idaho. Results of the RMRS experiments determined that a blend of wood-strands performed as well as agricultural straw in controlling erosion from a granitic soil. Two different wood-strand blends achieved 97-98 percent reduction in sediment delivery at an application rate of 70% ground cover on a 30% slope at high rainfall rates (Foltz and Dooley, 2003). Although minimally acceptable sediment loss rates were achieved at application rates as low as 40% cover under laboratory conditions, they are unlikely to be achievable under field conditions.

Relying on the success of conceptual designs and laboratory tests, the USDA SBIR program and the USFS WO subsequently supported and intensive two-year development and validation effort. In the middle of that effort, the Hayman Fire occurred near Denver, CO. The USFS requested that we make approximately one-ton of a “July 2002 best solution” wood-strand mulch for field trials in Colorado. The material was delivered to Dr. Peter Robichaud in mid-July and deployed in early August 2002 at a field experiment on the Hayman Fire site in Colorado. The application rate was approximately 70% soil cover. Robichaud’s FY2004 progress report suggested that the wood-strand material plots had significantly lower sediment output than straw mulched plots on the Hayman fire site (Robichaud and Wagenbrenner 2005).

Mathematical modeling of surface water hydrology at the millimeter scale and physical prototyping by Forest Concepts suggested that it might be possible to substantially exceed the functional performance of agricultural straw and other commercially available mulch products with an engineered wood-strand material. It appeared that physical properties such as strand shape and thickness, as well as blends of components with diverse physical properties could be optimized for particular slope, soil, and climatic conditions.

Figure 1. Agricultural wheat straw at 70% soil cover.

Figure 2. A "look alike" 2002 prototype blend of engineered wood-strand material at 70% soil cover.

Following modifications to the wood-strand design, a second round of experiments at the USFS lab was completed in 2003-2004 to further evaluate the effects of wood-strand properties. Variables examined in a series of factorial experiments were: strand length (160, 80, and 40 mm), 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 50 mm/hr plus two levels of added overland inflow beginning 15 minutes into the trial.

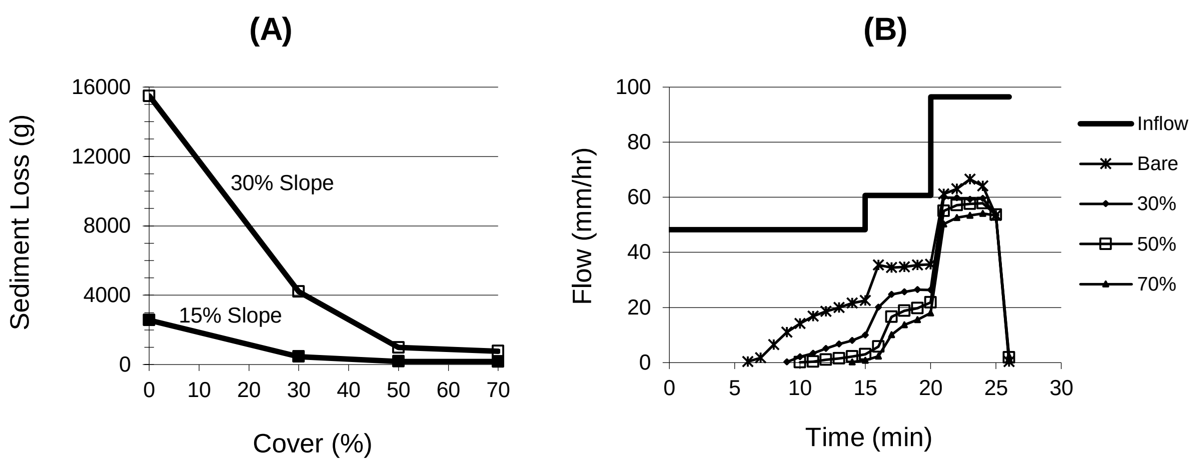


Figure 3. Sediment loss (A) and runoff hydrograph (B) for varying cover amounts of wood strands (Yanosek, Foltz et al. 2006).

The USFS data (Yanosek, Foltz et al. 2006) shows that very effective erosion control can be obtained at 50% ground cover. This compares favorably to equivalent 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 mulched with wood strands. Reduced runoff due to increased infiltration provides more soil moisture to support plant growth and reduces the risk of downslope flooding.

The wood-based material was proven to perform the erosion control function as well as wheat or rice straw without being a potential source of non-native weeds, agricultural pesticide residues, and other foreign materials in pristine forest areas (Foltz and Dooley 2003). While the functional performance of the wood-strand material has been demonstrated to be equivalent to wheat straw, other factors were observed that may cause secondary-effect benefits. For example, equivalent sediment control is attained by the wood-strands at substantially lower ground cover rates than for wheat straw mulch. Increased open areas may encourage native plant emergence.

A first proof of concept study for the wind erosion control potential of wood strands was conducted during the 2005/06 academic year at the USDA ARS laboratory in Pullman, WA. Dr. Joan Wu and Dr. Brenton Sharratt guided graduate student (Ms. Natalie Copeland) to test the efficacy of wood-strand materials under laboratory wind tunnel conditions.

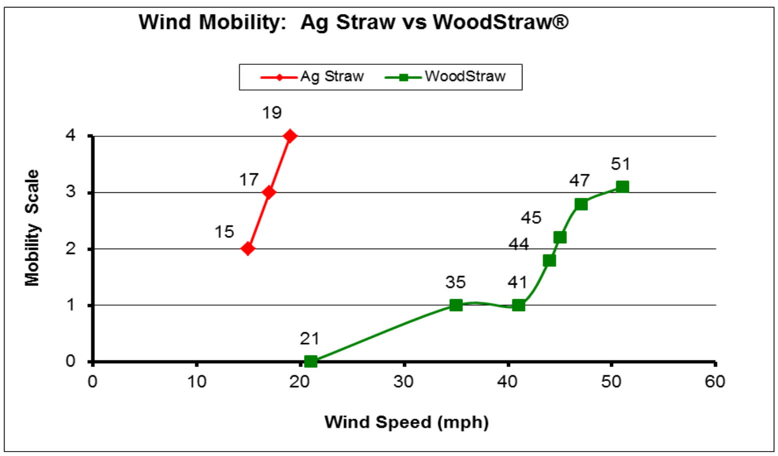
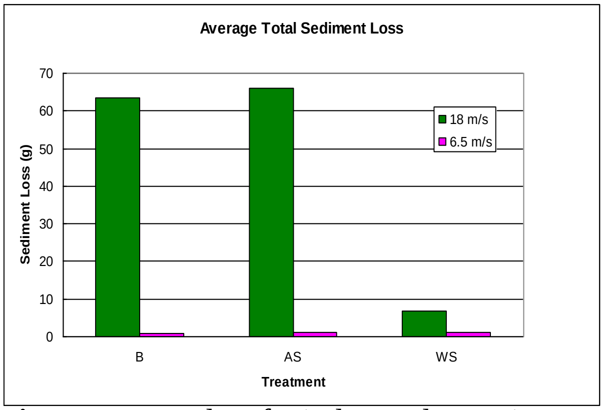
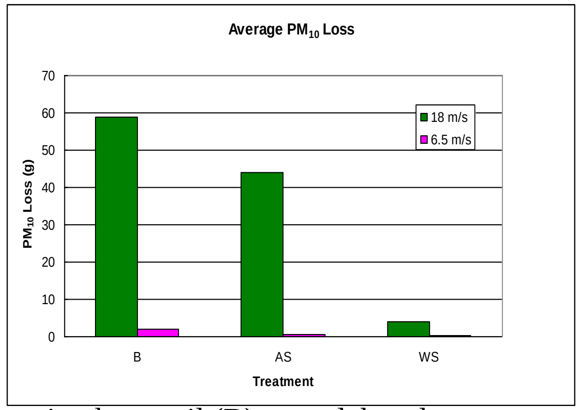


Figure 4. Results of an experiment at USDA ARS laboratory in Pullman, WA showing the threshold velocity for wheat straw versus one wood-strand blend under wind tunnel conditions (Copeland, Sharratt et al. 2006). At a movement score of 3, mass mobilization of the material begins, and at score of 4 all material is lost from the plot.





Figures 5. Results of wind tunnel experiments comparing bare soil (B) to mulches demonstrate that wood strands (WS) of the type tested are more effective than straw mulch (AS) for controlling both total sediment and fine PM_{10} dust emissions (Copeland, Sharratt et al. 2006).

The charts above clearly demonstrate the potential for wood-strand wind erosion control materials to effectively reduce wind erosion from graded soil. As discussed earlier, the effectiveness of any mulch material is determined by its mobility at target wind velocities. The charts above show that at low 6.5 m/s wind speed (2 day occurrence event in central Washington) the straw mulch stayed in place and performed well. However, at the 18 m/s wind speed (2 year occurrence under central Washington conditions) the agricultural straw mulch treatment actually increased total sediment. This was attributed to the straw acting as a soil surface abrader when it blew off of the plot. This finding reinforces the need to develop wind erosion control mulch materials that are wind-stable at target wind speeds.

Section 4. Resulting Engineered Wood-Strand Mulch (aka WoodStraw® ECM)

Design and specification of the commercial version of wood-strand erosion control materials followed the Appreciative Design Method developed by Dooley and Fridley in the 1990s (Dooley and Fridley 1996; Dooley and Fridley 1998; Dooley and Fridley 1998). The design method engaged end users, and constraint owners throughout the production, distribution, transport, and application supply chain. Stakeholders defined operational objectives and constraints that surrounded the technical criteria and design features established during the joint USFS RMRS and Forest Concepts research program.

The commercial grade material (subsequently called WoodStraw® ECM) was optimized for:

- Minimizing rainfall triggered sediment loss from slopes of at least 30% on highly erosive soils.
- Minimizing dust generation from exposed soils at winds to at least 40 miles per hour.
- Minimizing rill formation and propagation on slopes to 30%
- Ability to be baled into regular and large square bales for handling similar to agricultural straw
- Ability to be applied by straw blowers designed for straw bales.

The engineered wood-strand erosion control material incorporates functionality, shape, and composition that address the known limitations of agricultural straw and meets the functional requirements of public agency cooperators:

- Manufactured from clean wood to be ecologically compatible with forested and brush covered landscapes, be inherently weed-free, and free of pesticide residues.
- Designed as a multi-part blend of strands that are stable at design cased winds of 18 m/s as well as stable on hillslopes subjected to overland flow.
- Demonstrated to prevent or minimize rill formation and propagation. (photo at right)
- Demonstrated to reduce sediment loss by at least 85% in laboratory experiments using highly erosive soils.
- Packaged in bale form to be compatible with straw bale infrastructure and straw blowers.
- Can be applied or blown at high moisture to minimize dust creation.

Figures 6. Wood-strand erosion control material on test plots applied at 70% soil cover.

Early in 2005, product engineers and business managers at Forest Concepts, as well as advisors from the USDA Forest Service and BLM, concluded that the new wood-strand erosion control mulch had achieved all design objectives and performance criteria. The material was approved by the interagency Burned Area Emergency Response (BAER) national program leader for use as a post-wildfire erosion control material beginning with the 2005 fire season. Since then the material has been used in all nine western states.

Section 5. Field Trials with Wood-Strand Erosion Control Material

A series of studies comparing shredded forest residuals, agricultural straw, and WoodStraw® wood-strands was installed by Dr. Randy Foltz on road obliteration sites in Idaho (Foltz 2012). The target application rate was 50% soil cover since the slopes were relatively shallow. Although both the agricultural straw and shredded wood materials quickly disappeared, the wood-strand mulch was persistent. After three years, the wood strand treatment had the highest average sediment mitigation.

A frequent question asked about wood-strand and other mulches is their effect on soil nitrogen. The USDA Forest Service, Rocky Mountain Research Station began a long-term soil-effects study in 2005 on the School Fire site in southeastern Washington (Berryman, Morgan et al. 2014). The study compared plots that were untreated, mulched with wheat straw, and mulched with wood-strands (WoodStraw® ECM). All of the mulch treatments were surface-applied and not tilled into the soil. Mulch cover was expected to reduce soil water evaporation, improve soil aggregate stability, and maintain soil porosity (Mulumba and Lal 2008). Higher soil moisture during the warm season also increases microbial activity with consequential increased organic matter decomposition.

The Berryman study ran for four years. Findings were that surface mulching significantly increased soil organic matter, soil carbon, and soil nitrogen – even though none of the materials were tilled into the soil. The wood-strand material resulted in substantially higher organic matter, carbon, and nitrogen than the wheat straw plots, but the differences were not statistically significant due to small sample size.

This study also confirmed the perceived "nitrogen metering effect" of durable mulches such as wood-strands compared to short-lived mulches such as straw. The carbon:nitrogen (C:N) ratio for the wheat straw was 142 at the time of application and declined to 50.8 after four years. In contrast, the wood-strand mulch began at C:N ratio of 532 and after four years had declined to 214. This suggests that the wood mulch will continue to support microbial action for many years to come.

Mountain Pine Manufacturing, in cooperation with Colorado Department of Transportation (CDOT), installed a test of wood-strand mulch made from beetle-killed pine wood. The wood-strand erosion control material was demonstrated to perform well on a 51% slope road embankment that was too long of a slope-length for effective blowing. In this case, bales were placed on a grid to ensure even distribution and then spread by an experienced crew.

Figures 7. Hand application of wood-strand mulch at 70% soil cover on a 51% slope in Colorado in a CDOT test and follow-up two months later.

The CDOT study showed the effectiveness of wood-strand mulch to reduce sediment loss from the slope and prevent rills from forming.

Monitored field studies of post-fire mulching treatments including wheat straw, hydromulch, and wood strand mulch (WoodStraw®) were summarized in a 2013 report (Robichaud, Lewis et al. 2013). The report included the very first wood-strand testing on the Hayman fire in Colorado in 2002, and subsequent plots that included production-grade wood-strand mulch on the 2005 School fire in Washington. Measured application rates of the wood-strand mulch on the Hayman and School fire were 51 and 54% soil cover respectively. On the School fire, rapid revegetation by natural plants and applied seeds stimulated by adequate rainfall provided effective erosion control on all treatments after the first year. Effective performance over multiple years on the Hayman fire was attributed to the long performance life and stability of the wood-strand mulch compared to other treatments.

Section 6. Operational Uses of Wood-Strand Mulches

Engineered wood-strand erosion control mulch was first commercially produced and marketed in 2005 under the WoodStraw® trademark. It is now manufactured in Colorado under the Blue-Straw™ brand name. Wood-strand erosion control mulch (US Patent 6,729,068) is increasingly a preferred alternative to agricultural straw mulch as well as the more expensive rolled erosion control blankets for both water and wind erosion control on many high-value sites. More than 15,000 tons of material have been applied to approximately 300 projects on public and private lands of the United States.

The initial market for WoodStraw® and related wood-strand mulches was on wildfires and abandoned mine land reclamation. Large volumes of the material were applied on the following representative fires:

- King Fire – Sacramento, CA (dozer line repair under power lines)
- Snake One – Weiser, ID (BLM)
- Fourmile Canyon – Boulder County, CO (NRCS/County)
- Castle Rock – Ketchum, ID (USFS)
- School – SE Washington (USFS)
- Pilot Peak – UT (BLM)
- Angora – Lake Tahoe, CA (USFS)
- Barnes Canyon – Caliente, NV (BLM)
- Black Butte – Sisters, OR (USFS)
- Rim Fire – Yosemite, CA (suppression rehab)

Figures 8. Left - wood-strand mulch applied to the Barnes Canyon fire site in Nevada. Right – wood-strand mulch applied to the Fourmile Canyon fire site in Boulder, CO.

The majority of the post-wildfire use has been for helimulching on high severity burned areas with either critical resources downslope or exposure to high winds. The above photo from the Barnes Canyon fire site in Caliente, NV shows application on an area of severe burn just above the primary east-west rail line that connects southern California with the rest of the U.S. The use on the Fourmile Canyon fire was in areas subject to high winds typical of the forest slopes near Boulder, CO.

Figures 9. Left – delivery of baled wood-strand mulch from manufacturing plant. Right - Helimulch base on the Clearwater National Forest surrounded by baled WoodStraw® ECM.

Delivery of helimulch sized bales is typically via long-haul truck directly to a staging area as shown above. The photo on the right demonstrates a beneficial practice of lining the helipad with baled material to minimize the effects of prop wash on surrounding areas. This photo also shows how the contractor used equipment to break up the bales and loosen the wood-strand material (and agricultural straw in other sites) to ensure more even flow from the nets during application.

Figures 10. Left - Hand application of wood-strand mulch on the Cloud Cap Fire. Right – staging bales of wood-strand mulch near homes for hand application on the Angora Fire site.

Hand application of wood-strand erosion control mulch on firelines for suppression rehab, along drainages, adjacent to roads, and around homes is common. Smaller 50-60 pound bales are available staked 20 or 24 bales per pallet to enable staging, handling, and distribution to dispersed application sites. The bale weight makes it much easier to carry than typical 80-110 pound agricultural straw bales. Applicators often comment that the wood-strand bales are easier to spread than agricultural straw and are not dusty. Unlike the case with agricultural straw, dust and allergens are rarely an issue with field crews working with wood-strand mulch.

Figures 11. Left – Blowing wood-strand mulch on Payette Forest with large straw blower. Right – Mixed load of large helimulch bales and small bales of wood-strand mulch ready for delivery.

WoodStraw® wood-strand mulch is certified by straw blower manufacturers for use in large and small straw blowers. Blowing is an efficient method to apply materials alongside roads as shown above on the Payette National Forest. When a project calls for both large helimulch bales and smaller bales for human handling, mixed truckloads can be prepared as shown above right.

Figures 12. Left – Helimulch wood-strand material on snow in the Snake River canyon. Right – Helimulch application of wood-strand mulch over snow layer on BLM Barnes Canyon fire. Mulch will lay on ground as snow recedes in the spring.

A common question that arises in the fall, particularly for projects where funding is delayed until the start of a new fiscal year, is whether it is effective to apply wood-strand mulch on top of snow. The photo above left shows application in steep draws above the Snake River in Oregon just after an early-fall snow event. The objective was to reduce overland flow as the snow melted, and encourage germination of seeds between when this early snow disappeared and the main winter snow began. Among the first over-snow uses was on the Barnes Canyon fire in Nevada shown above right. At that site, the material was applied on top of at least 6 inches of snow. Here, the snow was likely to melt from the bottom of the site up the slope as the weather gradually warmed over a period of weeks in the spring. It was critical to protect the slope and support establishment of grasses as soon as the lower slope became exposed and warmed and while the upper slopes were still snow covered. There was also a belief was that the layer of mulch on the upper slope may slow snow melt by blocking sunlight and thus further reduce overland flow to the critical lower slopes above the railroad.

Many large fires do not need blanket application of erosion control mulches. Particularly in areas with wide streamside benches, the only need is to capture sediment and reduce overland flow into seasonal creek channels. The Willow Creek fire on BLM land in Nevada is such a case. Helicopters were used to tactically apply strips of WoodStraw® erosion control mulch.

Figure 13. Helicopter application of WoodStraw® to form sediment capture strips along seasonal creek on BLM Willow Fire. Multiple passes make the stripe wider at low points with higher expected flow.

Section 7. Conclusions, Acknowledgments, and Literature Cited

Disciplined science and engineering has resulted in highly effective wood-strand mulches to replace agricultural straw for erosion control. Seven years of operations use demonstrate that the wood-strand mulch provides viable erosion control while providing additional benefits of being weed-free, long-lasting, and wind-resistant.

Although application rates as low as 40% were proven to provide minimally acceptable rainfall and wind erosion control under laboratory conditions, highly effective performance under field conditions with variable slope and weather have occurred most often at application rates of 50-70% soil cover depending on the resources at-risk.

Acknowledgments

We would like to express our appreciation to the USDA NIFA SBIR Program for their support and encouragement. This work was supported in part by the USDA NIFA Small Business Innovative Research Program contracts 2002-33610-11874, 2003-33610-13997. Any opinions, findings, and conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

The United States Forest Service provided financial assistance to the Rocky Mountain Research Station to support the development and testing of the wood-strand alternative to agricultural straw. Technical support for development was provided by Drs. Randy Foltz, Peter Robichaud, and Bill Elliot of the USDA Forest Service Rocky Mountain Research Station.

Literature Cited

Associated General Contractors of Washington. (2002). "BMP C121: Mulching." Retrieved January 2, 2003.

Berryman, E. M., P. Morgan, et al. (2014). Post-fire erosion control mulches alter belowground processes and nitrate reductase activity of a perennial forb, heartleaf arnica (*Arnica cordifolia*). Research Note RMRS-RN-69. Fort Collins, CO, US Department of Agriculture, Forest Service, Rocky Mountain Research Station**:** 10.

Bisson, P. A., G. H. Reeves, et al. (1997). Watershed management and Pacific salmon: Desired future conditions. Pacific Salmon and Their Ecosystems: Status and Future Options. New York, Chapman and Hall.

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

Burroughs, E. R. and J. G. King (1989). Reduction of soil erosion on forest roads. General Technical Report INT-264. Ogden, UT, USDA Forest Service.

Copeland, N. S. (2007). Evaluating a wood-strand material of wind erosion mitigation and air quality protection. Master of Science, Washington State University.

Copeland, N. S., B. S. Sharratt, et al. (2006). Evaluating material properties to optimize wood strands for wind erosion control. ASABE Paper No. 062199. Presented at ASABE international Meeting, Portland, OR., St. Joseph, MI. American Society of Agricultural and Biological Engineers**:** 9.

Copeland, N. S., B. S. Sharratt, et al. (2009). "A Wood-Strand Material for Wind Erosion Control: Effects on Total Sediment Loss, PM10 Vertical Flux, and PM10 Loss." Journal of Environmental Quality **38**: 139-148.

Cox, C. (1998). "Herbicide Factsheet: Clopyralid." Journal of Pesticide Reform **18**(4): 15-19.

de la Fuente, M. (2002). Clopyralid and Compost in California. Santa Clara, CA, University of California Cooperative Extension**:** 4.

Dooley, J. H. (1994). Changing public expectations and their effect on engineering in the natural resource industries. Incorporating Biological Science Technology in Processing, Machine and Natural Resource Systems Designs, Manhattan, Kansas.

Dooley, J. H. (2000). Collaborative Design of Fish Habitat Enhancement Projects in Streams and Rivers of Washington State Ph.D. Dissertation, University of Washington.

Dooley, J. H. and J. L. Fridley (1996). Appreciative Design: incorporating social processes into engineering design. Paper 965004. St. Joseph, MI, American Society of Agricultural and Biological Engineers.

Dooley, J. H. and J. L. Fridley (1998). Application of social network analysis to forest engineering design decisions. Paper 987023. St. Joseph, MI, ASAE.

Dooley, J. H. and J. L. Fridley (1998). Influence of social networks on engineering design decisions. Proceedings of the 1998 Annual Conference of the American Society for Engineering Education. Washington, DC, American Society for Engineering Education.

Dooley, J. H. and K. M. Paulson (1998). Engineered large woody debris for aquatic, riparian and upland habitat. Paper 982018. St. Joseph, MI, ASAE.

Dow AgroSciences (2002). Important news about clopyralid herbicides and compost: InfoSheet for wheat growers. Indianapolis, IN, Dow AgroSciences**:** 2.

Dow AgroSciences (2007). Tordon 202C Liquid Herbicide: Specimen Label. Calgary, Alberta, Dow AgroSciences**:** 10.

Dow AgroSciences (2008). Curtail M Herbicide: Specimen Label. Indianapolis, IN, Dow AgroSciences**:** 9.

Dunne, T. and L. B. Leopold (1978). Water in Environmental Planning. New York, W.H. Freeman.

Ellison, W. D. (1944). "Studies of raindrop erosion." Agricultural Engineering **25**: 131-136, 181-182.

Fife, L. and W. Miller (1999). Rice straw feedstock supply study for Colusa County California. Woodland, CA, Rice Straw Feedstock Joint Venture.

Foltz, R. B. (2012). "A comparison of three erosion control mulches on decommissioned forest road corridors in the northern Rocky Mountains, United States." Journal of Soil and Water Conservation **67**(6): 536-544.

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

Fritz, C. (2008). ESR Monitoring Report: Snake One (B19E) Fire. Boise, ID, USDI, Bureau of Land Management, Boise District**:** 10.

Gaolach, B. (Undated). Copyralid herbicide and compost. Renton, WA, Washington State University Extension**:** 2.

Govers, G., I. Takken, et al. (2000). "Soil roughness and overland flow." Agronomie **20**: 131-146.

Granatstein, D. (2001). "Beware of herbicide contamination." Tilth Producers Quarterly: A Journal of Organic and Sustainable Agriculture(Fall 2001): 1-2.

Hare, M. E. (2007). "Choices in dust control: Stabilizing seaports, airports, and dusty roads." Erosion Control **14**(6).

Kline, R. (2000). Estimating crop residue cover for soil erosion control. Soil Factsheet No. 641.220-1. Abbotsford, BC Canada, Resource Management Branch, Ministry of Agriculture and Food**:** 4.

Kullman, G., C. Piacitelli, et al. (2002). Control of Organic Dusts from Bedding Choppers in Dairy Barns. NIOSH Publication No. 97-103. Washington, DC, NIOSH, National Institute of Safety and Health**:** 2.

McGinley, S. (2002). Mine Tailings Restoration. 2002 Agricultural Experiment Station Research Report. Tucson, AZ, The University of Arizona College of Agriculture and Life Sciences**:** 18-19.

Mulumba, L. N. and R. Lal (2008). "Mulching effects on selected soil physical properties." Soil Tillage Research **98**: 106-111.

Raskin, L., A. DePaoli, et al. (2005). "Erosion control materials used on construction sites in California." Journal of Soil and Water Conservation **60**(4): 187-192.

Robichaud, P. R., J. L. Beyers, et al. (2000). Evaluating the effectiveness of postfire rehabilitation treatments. General Technical Report RMRS-GTR-63. Fort Collins, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station**:** 85.

Robichaud, P. R., S. A. Lewis, et al. (2013). "Post-fire mulching for runoff and erosion mitigation: Part I: Effectiveness at reducing hillslope erosion rates." CATENA **105**(0): 75-92.

Robichaud, P. R. and J. Wagenbrenner (2005). Hayman fire rehabilitation treatment monitoring progress report. Moscow, ID, USDA Forest Service, Rocky Mountain Research Station**:** 14.

Stout, J. E. (2004). "A method for establishing the critical threshold for aeolian transport in the field." Earth Surface Processes and Landforms **29**: 1195-1207.
Thompson, A. L. and L. G. James (1985). "Water droplet impact and its effect on infiltration." Transactions of the ASAE **28**(5): 1506-1510, 1520.
Washington State University and Washington State Dept. of Ecology (2002). Bioassay test for herbicide residues in compost: Protocol for gardeners and researchers in Washington State. Pullman, WA, Washington State University Extension**:** 6.
Whicker, J. J., J. E. Pinder, et al. (2002). Wildfire effects on contaminant transport through wind erosion: preliminary results. LA-UR-296. Proceedings of the Midyear Meeting of the Health Physics Society, Orlando, FL 18-20 February 2002. .
Wishowski, J. M., M. Mamo, et al. (1998). Decomposition parameters for straw erosion control blankets. Paper 982159. St. Joseph, MI, ASAE.
Yanosek, K. A., R. B. Foltz, et al. (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.