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# BIOBASED, BIODEGRADABLE GEOTEXTILES: USDA FOREST SERVICE RESEARCH UPDATE

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## ABSTRACT

Geotextiles are any textile-like material used for soil structural performance. From a worldwide geotextile market of approximately 700 × $10^6$ $m^2$, a small but growing percentage is biobased. Fiber options for biobased geotextiles include coir, jute, kenaf, flax, sisal, hemp, cotton, and wood fiber. Biobased geotextiles are used for short-term (6 month to 10 year) applications where biodegradability is a positive attribute. These geotextiles can be used as a mulch to increase plant growth and survival and control soil erosion. Sheet mulch may be incorporated with seeds that will germinate and take over the soil stabilization role as the geotextile biodegrades. Additional biobased geotexile applications include industrial and agricultural filters and oil and chemical spill absorbents. This paper presents a USDA Forest Service research update on biobased, biodegradable geotextiles.

## INTRODUCTION

Geotextiles are any textile-like material, either woven, nonwoven, or extruded, used in civil engineering applications to improve soil structural performance. The main functions geotextiles provide are aggregate separation, soil reinforcement and stabilization, filtration, drainage, and moisture or liquid barriers (Dewey 1993). The market for geotextiles is growing, with worldwide annual sales of more than 700 × $10^6$ $m^2$, which about 2% is biobased (Sen Gupta 1991). Many geotextile applications are permanent, and the use of biodegradable materials would have adverse results. However, other applications are temporary or short term, and the use of biobased, biodegradable materials is worthy of investigation.

Research in the area of biobased geotextiles is warranted for several reasons. Concern for the environment has made product biodegradability an issue. In addition, the USDA is interested in the development of nonfood, nonfeed alternative agricultural crops, many of which can be used in the production of geotextiles. Several lignocellulosic materials are applicable to the production of biobased, biodegradable geotextiles, such as kenaf, old corrugated containers, construction waste wood, jute, and others. Various biobased geotextile research projects have been conducted at the USDA Forest Service, Forest Products Laboratory (FPL), in cooperation with private industry, the USDA Agricultural Research Service, and other Forest Service research units (English 1992, 1993a,b). These research efforts have focused on temporary applications, such as sheet mulch for tree seedling survival and plant seed establishment, erosion control, and related applications of filtration and absorption. This paper presents an update of these research efforts.

## BIOBASED GEOTEXTILE PRODUCTION

Commercially, there is a good variety of geotextiles available that contain a majority percentage of biobased materials, which are selected for their low cost and biodegradability. Most geotextiles are used in erosion control where they serve to stabilize the soil surface while natural vegetation is established. Some geotextiles contain seeds to accelerate and control the regrowth. Most geotextiles contain some portion of synthetic material to hold the geotextile together. This is normally polypropylene nets or polyester scrim sheets that sandwich the biobased component. With an occasional exception, it is the goal of Forest Service research to make geotextiles from entirely biobased materials. For this purpose, FPL's Rando Webber[1] airlaid mat-making equipment was chosen.

In the Rando-Webber process, blended fibers are introduced into a high speed airstream by a toothed rotor called a lickerin. The air stream passes through a moving screen conveyor, depositing the fibers in a random fashion. From there, the fibers are mechanically entangled with barbed needles in a needle loom, producing a finished mat. To facilitate the needling process in FPL's simple needle loom, it is necessary to provide a scrim or backing sheet for the mat. For most research, recycled kraft paper is used.

## Kenaf as a Staple Fiber

Initial attempts at FPL to use kenaf as a staple fiber in nonwoven geotextiles were unsuccessful because the fibers broke during processing. Jute, a fiber similar to kenaf, is retted and oiled to make it pliable for woven and nonwoven fabrics. Environmental factors do not allow kenaf to be retted in the United States, but it does not preclude oil treatments. Machine modifications were made to further improve processing, and mats from kenaf were produced incorporating the following:

1. Soy oil was sprayed on the kenaf fibers in a paddle mixer. The fibers were aged in closed plastic bags for 2 weeks to allow the oil to penetrate and provide lubricity.

2. A coarse lickerin (1 tooth/2 $cm^2$) was installed in FPL's Rando-Webber and operated at about 20% of normal operating speeds. Retained fiber length increased from 1.2 to about 8 cm.

3. Relatively coarse needles of the type used to produce jute carpet backing were installed in the needle loom.

4. Optimum soy oil treatment levels were determined by making runs at 5, 10, 15, and 20 weight percent soy oil levels. Evaluation was based on the ability of the treated kenaf to be needle punched, handleability, water absorption, and tensile testing.

Needle punch evaluation was made by visually noting the amount of fiber breakage caused by the needles. Kenaf treated with 15 and 20 weight percent soy oil showed almost no breakage. At 10% treatment, some fiber breakage was noted but the amount did not seem excessive. At 5%, about half the fibers were broken. Handleability of all mats was about the same. Water absorption was not affected by the treatment levels tested.

Tensile testing was carried out according to ASTM standard D-4632 (ASTM 1986). Specimens of mat were cut into 10- by 20-cm rectangles and placed within a pair of 2.5- by 5-cm grips and tom apart at a machine rate of 30.5 cm/min. Specimens were tested in both machine direction (md) and cross-machine direction (cmd). In addition, strength levels were examined at ambient moisture content and after 24 h of soaking in water. Time and scheduling constraints did not allow examination of a complete matrix. Results are given in Table 1.

Notable is that tensile strength increased when the mats were soaked for 24 h. The deciding factor for choosing a treatment level, however, was the ability of the kenaf to be needle punched. As noted, at 10% the kenaf fiber exhibited only limited breakage, and this was the treatment chosen for the bulk of the research reported here. Although soy oil was chosen for the application discussed here, other oils also performed satisfactorily.

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[1]The use of trade names is for information only and is not intended to be an endorsement by the USDA Forest Products Laboratory.

**Table 1—Tensile test results of nonwoven kenaf geotextiles[a]**

| Soy oil (%) | Direction | Dry | Wet | Load To Failure (kg) |
|---|---|---|---|---|
| 5 | md | x | | 6.3 |
| 10 | md | x | | 6.7 |
| 10 | md | | x | 7.9 |
| 10 | cmd | x | | 7.2 |
| 10 | cmd | | x | 8.4 |
| 15 | md | x | | 4.5 |

[a] Values are average of five specimens.

## Selected Biobased Materials

In addition to kenaf, the following materials have been used by FPL to produce various biobased gcotextiles.

- Old corrugated containers (OCC) were shredded into 0.8-cm-wide strips and subsequently hammermilled using a 9.5-cm screen;. The OCC were chosen over old newspapers because of the concern of heavy metals in Sunday supplement inks.

- Construction waste wood (CWW) is wood waste from construction sites. It was hammermilled and reduced to fibers and fiber bundles by refining.

- Recycled jute fibers were obtained from old woven spice bags.

- Dahoma *(Piptadensiastrum africanum),* a tropical wood, was chosen for its rot resistance. It was flberized by refining. Dohama has an undetermined toxic effect, and its reuse is not recommended.

- Cotton fiber, was used primarily as a staple fiber and was recycled post-industrial scrap from the garment industry.

- Acetylated kenaf is more resistant to rot and decay than unacetylated kenaf. However, acetylated kenaf fibers are very brittle and they cannot be used as a staple fiber. Although relatively expensive and not ultra-violet stable, the process may help extend geotextile service life to some degree.

- Automotive carpet trim waste, a blend of polyester and polypropylene, was the only nonlignocellulosic fiber selected for study. It was selected primarily for its stable dark color.

Other materials, such as bagasse or coir, are also applicable.

## MULCH FOR TREE SEEDLING SURVIVAL

The survival of tree seedlings is a major concern to the USDA Forest Service and tree growers everywhere. Seedlings are commonly overplanted and thinned as they mature. In low survival rate areas, seedlings may have to be replanted, which is costly and time consuming. Environmental factors that affect seedling survival include moisture, temperature, light, chemical presence or absence, and mechanical damage. Mulches can be used to control most of these factors. A mulch is defined as “an application or creation of any soil cover that contributes a barrier to the exchange of heat or vapor” (Rosenberg 1974). Mulch works mainly by suppressing weed growth. This enables the sapling to make full use of light, moisture, and nutrients. The mulch also acts as a soil insulator and a vapor block. As a soil insulator, mulch helps keep the soil warm in the early and late part of the growing season. As a vapor barrier, the mulch acts to suppress evaporation.

Historically, the effectiveness of mulches on seedling survival has varied widely. Soil conditions, light, and longevity of the mat are contributing factors. In especially adverse conditions, survival has increased from near 0% to more than 90%. In typical situations, survival increases from 40% to 60% (McDonald and Helgerson 1990). To examine the use of mulches more closely, the Forest Service established a “Seedling Mulch Guidance Group.” The group is represented by foresters and researchers from National Forests, Research Stations, and the FPL.

Mulch materials can be categorized two ways: loose mulches and sheet mulches. Successful application of loose mulch, such as bark, sawdust, or straw, is largely dependent on thickness. Because loose mulch is bulky, it is most successful when seedling access is good, such as in an orchard or nursery; application in remote sites is limited.

Sheet mulch, on the other hand, can be rolled up or folded to allow packing into remote sites. Sheet mulch consists of woven or nonwoven materials or plastic film. Film mulch and most woven plastic mulch are less bulky than nonwoven mulch based on Iignocellulosic materials, but they have several disadvantages. Plastic mulch needs to be very well anchored to keep it from being dislodged by wind or animals. If dislodged, the mulch litters the forest or folds over and smothers the seedling. Plastic mulch suppresses weed growth reasonably well, but if not perforated, rainfall can be diverted from the seedling. Degradability of the plastics is also limited.

Key mulch characteristics for seedling survival have been identified. The mulch should be opaque to prevent weed growth and possess good insulative characteristics. The mulch should be porous for water infiltration yet retard water loss from underneath it. The mulch should be strong and durable enough to last until the seedling is well established, usually about 3 years. Good ground conformance would keep the mat from being dislodged. A biodegradable mulch will limit forest litter, save removal costs, and may increase mulch effectiveness. In addition, the mulch should be inexpensive and light weight for ease of transportation and installation.

The Forest Service Seedling Mulch Guidance Group decided to examine seedling survival, installation techniques, and associated costs with a variety of commercial and prototype sheet mulch materials. The FPL’s efforts focused on the production of a variety of biobased sheet mulches using FPL’s Rando-Webber. With minor exception, all mulches were approximately 90 by 90 cm with an “X” slit in the center for seedling placement. The mulch was held down with five metal staples, one in each comer and one in the center near the seedling. All sheet mulches, both experimental and commercial, were placed by foresters at the Southern Forest Experiment Station, Pineville, Louisiana; Wallowa-Whitman National Forest, Baker City, Oregon; Ochoco National Forest, Hines, Oregon; and the Lolo National Forest, Missoula, Montana. Mulches were placed in 1990, 1992, and 1993.

**Permeability**

The Forest Service Seedling Mulch Guidance Group requested that FPL test all 1993 mulches for water permeability, absorption, and run off. Of these three, permeability is the most important because it relates to the amount of rainfall immediately available to the seedling. Rainfall effects on slopes were of particular interest, and it was decided that the mats would be tested on a 30° slope. The fixture designed to do this testing consisted of a regulated sprinkler head and two tanks with tops cut at a 30° angle. One tank was designed to collect water that passed through the mulch and was covered with a 12-mm screen that supported the mulch and provided some level of ground contact simulation. The other tank collected run off. It was understood that this fixture was meant to provide some relative performance data and was not intended to be a direct simulation of rainfall.

Mulches at ambient moisture content were cut into 28- by 28-cm squares, weighed, and clamped onto the fixture. Water (1,000 g) was applied through the sprinkler head at a rate of 50 g/min. Two minutes after the water stopped, the mulch was reweighed and the water content in the two tanks was determined. Water not accounted for was designated "splash." Selected results of this work are shown in Table 2.

As noted, permeability of the mulch is a measure of how much water would be immediately available to the seedling. High run-off levels would indicate little water available to the seedling, although no measure was taken of water that might run under the mulch from above the slope. An overly absorbent material might trap all the water made available during a light rain.

**Table 2—Sheet mulch permeability data[a]**

| Sheet mulch type | Volume (%) | | | |
|---|---|---|---|---|
| | Absorbed by mat | Passed through bottom | Run off from top | Splash |
| IRT Brush Blanket | 0.4 | 0.4 | 98.3 | 0.9 |
| Easy Gardner Weed Block 6+ | 1.5 | 81.2 | 14.7 | 2.6 |
| Canfor Eco-Mat | 12.6 | 5.0 | 8.9 | 3.5 |
| Terra Enterprises | 6.0 | 6.0 | 83.2 | 4.7 |
| Dewitt Weed Barrier | 2.0 | 16.5 | 78.0 | 3.6 |
| Proseed grass mats w/ backing | 3.1 | 0.5 | 95.0 | 1.5 |
| Proseed grass mats w/o backing | 1.8 | 90.0 | 6.7 | 1.5 |
| Conwed EM 75 | 4.7 | 11.7 | 83.4 | 0.4 |
| Conwed 767 Poly 1/S | 11.5 | 0.0 | 81.5 | 7.1 |
| Conwed TLN 90 | 3.5 | 87.2[b] | 7.5 | 1.8 |
| FPL 80% Acet. Kenaf 20% Cotton | 3.6 | 0.0 | 87.2 | 9.2 |
| FPL Soybean Oiled Kenaf | 7.6 | 11.8 | 79.1 | 1.5 |
| FPL 70% Kenaf 30% Carpet Waste | .0 | 41.8 | 46.7 | 3.5 |
| FPL 80% Kenaf 20% Cotton | 5.0 | 2.5 | 82.6 | 9.9 |
| FPL 70% Wood Waste 30% Carpet Waste | 5.2 | 59.1 | 32.7 | 3.0 |

[a]Data may not add to 100% as a result of rounding.
[b]This mat disintegrated, allowing water to pass through.

Testing at FPL revealed that most mulches let less than 25% of the water pass; a few let no water pass, such as the Conwed 767 Poly 1/S and the FPL acetylated kenaf/cotton mulch. Other near zero values were obtained by the IRT brush blanket (0.4%) and the Proseed grass mats with backing (0.5%). Of course, actual field conditions may allow additional water under the mat. Best water passed values were obtained by Easy Gardner Weed Block 6+ (81.2%) and the Proseed grass mat without backing (90.0%). Relatively high values were also noted for the FPL kenaf/carpet waste and FPL wood waste/carpet waste mulches with 41.8% and 59.1%, respectively.

If results of this test were the only criteria for selecting mulch mats, the decision would be easy. However, field experience is what counts, and although this research is still ongoing and mostly unpublished, several general trends can be identified.

### Performance

First and foremost, the successful application of mulch to enhance seedling survival is site specific. If the site is especially remote, the bulkiness of the nonwoven biobased sheet mulch is a hindrance, and the plastic mulch would be preferred for installation, although more difficult to anchor. If reasonably accessible, biobased mulch offers good ground conformance and biodegradability. Few mats that are durable enough to last until the seedling is established have had adverse effects on seedling survival. Although if improperly installed, some plastic mulch will abrade the seedling stem and kill it. All FPL biobased sheet mulches are considered durable enough to last until the seedling is established, although some commercial biobased mats tested did not last one season. The economics of mulch installation are somewhat gray, and again, site specific. Sheet mulch installation costs range from less than \$800 to more than \$4,000 per $m^2$. Generally, if seedling survival rates are reasonably good and the site is accessible for maintenance, there is no reason to apply mulch. However, if the site has an inherently low seedling survival rate and is not readily accessible, the use of mulch has merit.

## SHEET MULCH FOR SEED INCORPORATION

The purpose of seed incorporated sheet mulches is to provide a vehicle for the distribution of seeds and prevent erosion during seed establishment and early plant growth. Commercial seed impregnated kenaf sheet mulch uses nonwoven polyester scrim sheets on both sides to hold the seeds in place. Other seed incorporated sheet mulches are made using cereal straw, kraft paper, and polypropylene netting. Because the objective of our research was to make completely biobased, biodegradable sheet mulch, alternative materials and seed incorporation techniques were examined. After preliminary examination, a mixture of 50% soy oil treated kenaf and 50% cereal straw was chosen for sheet mulch production. Three methods of seed incorporation were considered: (1) incorporating in the air-laying process, (2) incorporating prior to needle punching, and (3) preapplying to a kraft paper backing sheet using a starch-based adhesive.

Incorporating the seeds into the air-laying process resulted in the seeds gravitating to the bottom of the mulch, which is where they should be, but the seeds tended to fall out during production. Incorporating the seeds prior to needling was also ineffective because the seeds did not become sufficiently entangled to remain with the mat. However, preapplying the seeds to the kraft paper backing was quite successful. This was accomplished by spreading a thin layer of starch-based adhesive onto the backing, applying the seeds, and then feeding the mat onto the glued side. The combined backing and mat were then mechanically fastened together during the needlepunching operation. Gluing the seeds onto the backing not only helped the production process, it also insured that the seeds would not be dislodged during shipping or handling. Fertilizers and herbicides can be applied in the same manner.

Seed type and application rates were selected by an industrial cooperator and foresters in the Mount Baker-Snoqualmie National Forest in Washington state. Suggested rates were 2,000 to 4,000 wildflower seeds/$m^2$. The industrial cooperator selected a variety of rates for a plethora of grass and wild flower seeds. Twenty nine varieties of these sheet mulches were placed in a green house by the cooperator for evaluation. Seventeen different mulches were placed at high elevations in the Mount Baker-Snoqualmie National Forest in the fall of 1993 with germination to take place naturally in the spring of 1994. In total, 14 seed types were used.

Evaluation was made by visual inspection of germination rates and plant health. Evaluation of the cooperator mulch mats showed that the heavier mats (680 g/$m^2$) were marginally effective at establishing plant growth. However, the lightest weight mats (340 g/$m^2$) performed very well, with excellent germination rate and plant health. At this writing, the Mount Baker-Snoqualmie National Forest mats have not been evaluated because of snow cover.

## GEOTEXTILES FOR EROSION CONTROL

Sediment accounts for about 66% of the pollution in U.S. waterways. Most commercial biobased geotextiles target this problem. Various tests have been developed to measure the effect of geotextiles on erosion control. One commonly accepted method is to place a 1.2- by 1.2-m square of the geotextile on a slope and apply a measured amount of artificial rain. Sediment and water runoff are then measured by collecting them in troughs set beneath the geotextile. These tests are often conducted in the field where site-specific conditions, such as inherent soil type, can be considered. Table 3 lists the results of several mats FPL supplied to Dr. Arthur Peterson at the University of Wisconsin-Madison for erosion control testing.

All sheet mulches supplied performed exceptionally well as tested. The durability of these mats on seedling survival suggests that mats of this type should perform well to control erosion.

**Table 3—Sediment load in run off**

| Composition | Material weight (g/m2) | Time (min) | Sediment (g/L) |
|---|---|---|---|
| Check (no treatment) | | 0 | 3.640 |
| | | 60 | 0.840 |
| Soy-treated kenaf | 340 | 0 | 0.220 |
| | | 60 | 0.080 |
| Soy-treated kenaf | 680 | 0 | 0.740 |
| | | 60 | 0.040 |
| 70% soy-treated kenaf | 340 | 0 | 0.060 |
| 30% carpet waste fiber | | 60 | 0.060 |
| 70% soy-treated kenaf | 680 | 0 | 0.100 |
| 30% carpet waste fiber | | 60 | 0.060 |
| 70% soy-treated kenaf | 1,360 | 0 | 0.180 |
| 30% carpet waste fiber | | 60 | 0.060 |

## GEOTEXTILES FOR ABSORPTION AND FILTRATION

Two related applications of biobased geotextile are absorption and filtration. Geotextiles are used as soil filters, that is, they are installed to filter sediments from moving water. This function can be for both surface and ground water. Biobased geotextiles have application for surface water around construction sites where run off may be a problem and for industry where they can be used in waste water treatment. Use of biobased materials for absorption is expanding, with the largest use at this time to clean up oil and chemical spills.

Water soak tests were conducted at FPL to examine the water-holding capacity of sheet mulches when used as ground cover. Oil soak tests were conducted to examine the ability of the materials to serve as oil spill cleaners. Mats of selected materials were cut into 5- by 5-cm squares and weighed. Ten squares of each material were submerged in either water or 20 weight hydraulic oil for 10 min. After removal, the samples were placed on a screen or blotter to let excess fluid drain. After 10 min, the samples were reweighed and evaluated on a weight gain ratio and averaged (Table 4). Results are consistent with other biobased materials used for absorption. Use of similar materials is finding commercial application.

**Table 4—Average weight gain during water and oil soak test**

| Material | Water (g water/g material) | Oil (g oil/g material) |
|---|---|---|
| 80% kenaf/20% cotton | 7.2 | 6.7 |
| 90% OCC/10% cotton | 7.5 | 7.1 |
| 90% CWW/10% cotton | 10.1 | 9.5 |
| 100% recycled jute | 11.2 | 8.1 |
| 90% Dahoma/10% cotton | 4.7 | 4.5 |
| Kenaf with 10% soy oil treatment | 3.4 | na |

## CONCLUSIONS

The market for biobased goetextiles is small but growing and is driven by the environmental benefits of these types of products and the need to make these products biodegradable. Some conclusions from our research follow:

- A variety of lignocellulosic materials are applicable to produce biobased, biodegradable geotextiles.
- Kenaf fibers can be treated with soy oil and successfully used as a staple fiber in the production of biobased geotextiles.
- Depending on site-specific variables, biobased geotextiles are effective in increasing tree seedling survival rates.
- Seeds, fertilizers, and herbicides can be incorporated into biobased sheet mulches by adhering the seeds to a kraft paper backing using a starch-based glue and needle punching the backing to the mulch material.
- Biobased geotextiles can be effectively used to control erosion while plant growth is established.

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