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ENGINEERING AND GINNING

Screening Study of Select Cotton-based Hydromulch Blends Produced Using the Cross-Linked Biofiber Process

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ABSTRACT

Research has shown that hydro-mulch containing specific blends of cotton, mixed with other agricultural by-products, is effective in providing protection from rainfall induced erosion of soil surfaces prior to establishment. To evaluate the potential of utilizing the Cross-Linked Biofiber Process to incorporate low value biomass byproducts into an effective hydro-mulch blend, a cooperative research program was conducted between the United States Department of Agriculture and Colorado State University. Following construction of a rainfall test facility, a series of hydro-mulch blends containing various biomass components were tested under controlled rainfall intensities. Biomass components included material derived from cotton, wheat, sudan hybrid (Haygrazer) and other agricultural residues. In addition, a popular commercially available hydro-mulch used on slopes of 3:1 or greater was used as a control. Analysis of the soil and organic content of runoff collected was conducted and blend constituents evaluated for their effectiveness in providing protection against rainfall induced soil erosion. Dunnett's multiple range and Kruskal-Wallis statistical tests were used to evaluate results and eliminate treatments not significantly different from the control. Eight of the eleven treatments evaluated were significantly different from the control in at least one of the metrics - soil runoff, organic runoff, or total runoff. Three were not significantly different from the control in any of the three metrics. Two treatments were selected for further research and development.

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According to the United States Environmental Protection Agency's (USEPA) 2004 Water Quality Report to Congress, sediment/siltation is a top cause of impairment in assessed rivers and streams. "Excess sediments, siltation; affects aquatic communities by altering and suffocating habitat and clogging fish gills." (USEPA, 2004). Sediment laden runoff can also carry chemical pollutants (Risse and Faucette, 2001),. Sediment itself fills up storm water conduits diminishing capacity, and ultimately contributing to the premature filling of reservoirs with sediment, effectively ending the usefulness of the reservoir (Ponce, 1989). Human disturbances of the natural soil surface contribute greatly to this siltation, and sedimentation, at construction sites contributes disproportionally. Due to the often-necessary elimination of the natural vegetation and ground cover, the exposed, bare soil on construction sites causes soil loss rates that can be 10 to 20 times greater than that of agricultural lands (USEPA, 2000). In 2003, the federally dictated National Pollutant Discharge Elimination System (NPDES) Phase II program took effect requiring storm water management plans for all activities disturbing more than 0.40 hectare.

In an effort to comply, construction activity erosion best management practices (BMPs) are designed and implemented to prevent erosion and reduce quantities of sediment transported offsite. There are many types of erosion control products on the market today. A common, temporary BMP option that is utilized during the period between soil disturbance and revegetation is mulch. Straw, shredded paper, wood chips and gravel have all been widely used for mulching (Agassi and Ben-Hur, 1992; Buchanan et al., 2002). The long term goal of erosion control products should always be establishment of a permanent vegetative cover, and grass seed is frequently mixed with mulch to accelerate revegetation while providing temporary cover (Flanagan et al., 2002a). The effectiveness of surface mulching has been well demonstrated.

When applied to a recently disturbed site, mulch can reduce erosion by absorbing moisture and intercepting rainfall energy, which reduces soil surface sealing, particle detachment and runoff potential (Lattanzi et al., 1974; Mannering and Meyer, 1963). Mulches also reduce overland flow velocities once runoff occurs (Kramer and Meyer, 1969; Meyer et al., 1970; Meyer et al., 1972).

In earlier studies (Holt et al., 2005a; Holt et al., 2005b) mulches created from by-products of the cotton ginning industry were evaluated at a relatively low slope (9%) using both hand application and a truck-mounted style hydro-mulcher. These were evaluated concurrently with wood and paper hydro-mulches commercially available as ready-to-use products from construction material vendors. The product application rates were 1,121 kg/ha, 2,241 kg/ha or 3,362 kg/ha with rainfall intensities of 6.35 cm/hr or 10.41 cm/hr. The cotton-based products performance was equal to or better than wood and paper mulches in reducing soil loss during simulated rainfall.

The purpose of this study was to evaluate blends of agricultural by-products with cotton gin by-products (CGB) using the Cross-Linked Biofiber Process (Holt et al., 2010) in comparison to a popular commercially available hydro-mulch used on slopes of 3:1 or greater. The Cross-Linked Biofiber Process creates a use for cotton and other agricultural by-products by fiberizing and entangling them in a 3-dimensional matrix creating a material that may potentially be used in items such as mulches, insulation or animal bedding.

MATERIALS AND METHODS

The study was performed at the Hydraulics Laboratory located at the Engineering Research Center (ERC) of Colorado State University (CSU) in conjunction with USDA-ARS, Cotton Production and Processing Research Unit (CPPRU) in Lubbock, Texas. The water supply to the research facilities is furnished by Horsetooth Reservoir, which is adjacent to the ERC. Approximately 46 m^2 of the indoor portion of the Hydraulics Laboratory was dedicated to rainfall simulation while soil preparation and hydro-mulch application were conducted in an auxiliary building and outside, respectively.

Cotton-based Hydro-mulch Blends. The cotton-based hydro-mulch blends all contained some percentage of processed cotton gin by-products and other agricultural residue. The exact mixtures of the tested blends are considered confidential by the commercial cooperator who funded the research, Landmark Earth Solutions, Incorporated. The commercially available control contained wood fibers and the eleven cotton-based blends evaluated contained some percentage of cotton burrs and cotton stalks/sticks. All of the cotton by-products and agricultural residues in the blends were processed through an attrition mill at CPPRU. The attrition mill created fibers from the materials instead of chopping or excessively reducing length. The treatment blends are listed in Table 1. Once all the cotton by-products and agricultural fibers were processed, they were stored in a cool dry location until being shipped to CSU.

Table 1. Cotton-based hydro-mulch blends evaluated.

Treatment[z]	Items in the cotton-based Hydro-Mulch blends[y]
AG1	Agricultural residue, cotton byproducts, cotton fiber, polyacrylamide. Particles less than 20 mesh removed.
AG2	Agricultural residue, cotton byproducts, cotton fiber, polyacrylamide. Particles less than 20 mesh removed.
AG3	Agricultural residue, cotton byproducts, cotton fiber, polyacrylamide.
HG1	Haygrazer, cotton byproducts, cotton fiber, polyacrylamide
AG4	Agricultural residue, cotton byproducts, cotton fiber, polyacrylamide
AG5	Agricultural residue, cotton byproducts, cotton fiber, polyacrylamide, tackifier.
CS1	Cotton stalks, cotton byproducts, cotton fiber, polyacrylamide
HG2	Haygrazer, cotton byproducts, cotton fiber, polyacrylamide
AG6	Agricultural residue, cotton byproducts, cotton fiber, polyacrylamide, tackifier.
AG7	Agricultural residue, cotton byproducts, polyacrylamide
WG1	Wheat straw, cotton byproducts, cotton fiber, polyacrylamide

[z] AG = Agricultural residue (same residue, seven different blends); HG = Haygrazer; CS = Cotton stalks; WG = Wheat straw.

[y] All agricultural residues, haygrazer, wheat straw, cotton stalks, and cotton byproducts were fiberized through an attrition mill.

Thirty-nine soil plots under simulated rainfall experiments were treated in CSU's Hydraulics Laboratory. Experiments consisted of eleven different formulations and one control (e.g. commercially available hydro-mulch used on slopes 3:1 or greater). Experimental phases were soil plot preparation, hydro-mulch mixing and application, rainfall simulation and discharge collection and runoff evaluation.

Soil Plot Preparation. Soil used for this study was a sandy loam consisting of 72% sand, 19% silt and 9% clay as classified by the USDA soil classification system. Prior to use, all soil was processed on a shaker table (sieved) with a 6.25 mm screen size and stored in large woven polypropylene sacks located in a climate-controlled environment. Soil plots were contained in steel trays which measured 0.61 m wide by 3.05 m long and 7.6 cm deep. Clean, dry trays were each filled with 186 kg of sieved soil and wetted to the optimal moisture content, 8-12%, as determined by the Proctor compaction test (ASTM – 2007). The soil surface was then leveled and compacted using a vibratory plate compactor and hand tampers. Soil was compacted to an average bulk density of 1.43 g/cm^3. Bulk dry density was verified using three randomly located soil samples of known volume from each tray. Voids created in the soil surface during this process were backfilled and compacted with extra soil removed during the leveling process. Trays were then immediately moved to the hydro-mulcher.

Hydro-mulch Application. The hydro-mulcher used has a mixing tank capacity of 1,628 l. A photo of the hydro-mulch application machinery is presented in Figure 1. Each unique hydro-mulch blend evaluated was mixed using 302.8 l of water for a minimum of 10 minutes to ensure enough volume and time for proper mixing in the hydro-mulcher. Commercially available hydro-mulches were mixed according to manufacturer's specifications. Hydro-mulch was applied at 2,242 kg/ha. Uniformity was accomplished using an overhead gantry carrying the hydro-mulch applicator hose. For each unique hydro-mulch blend, the spray pattern width and the time to apply 75.7 l was determined. Using this information and a variable frequency drive motor to control applicator hose speed on the gantry, uniform application rates were achieved. Once the hydro-mulch was applied, trays were moved into a climate controlled environment and allowed to dry for 48 hours prior to testing.

Figure 1. Hydro-mulch application gantry system.

Testing. Prior to rainfall simulation, three trays containing prepared soil were placed under the spray nozzle and elevated to a 2H:1V (horizontal: vertical, 50%) slope leaving the highest point of each tray approximately 3.96 m below the spray nozzle (Figure 2). Rainfall simulation was performed using a stainless steel nozzle, which produced a conical spray pattern and the manufacturer's estimated drop size of 563 µm at 1.30 kPa . Uniform coverage of the soil plots was verified using the Christiansen Coefficient of Uniformity, (CU) (Christiansen, 1942) method and 6 graduated cylinders magnetically attached to each box (18 total graduated cylinders) containing the soil plots. The average CU for all tests was 85 with a standard deviation of 2.8. Using ASTM 6459 (ASTM – 2006) as a guide, where peak average rainfall intensity called for is 150 mm/

hr, measured test average rainfall intensity for this study was 145 mm/hr. Filter bags capable of capturing 10-micron size particles were placed at the base of each soil plot to filter all particle runoff. The filter bags were labeled, dried and pre-weighed prior to use. Video and time lapse photography with a one minute interval was initiated. Water pressure of approximately 1.44 kPa with a flow rate of approximately 37.9 l/min were set and rainfall simulation began. All product treatment tests were 45 minutes in length. During testing, time of initial runoff for each tray was recorded. In addition, a filter bag would be changed and the time recorded prior to overflowing if necessary. Upon conclusion of testing, the spray nozzle was immediately isolated to prevent dripping onto the soil surface to preserve surface integrity. Graduated cylinder location and volume was recorded for rainfall intensity calculation and filter bags were hung to air dry. Once dry, filter bags were packaged and sent to the CPPRU in Lubbock, Texas for soil and organic matter analyses.

Figure 2. Triplicate soil plot test configuration.

Laboratory Analysis. At the CPPRU, the filter numbers were recorded and the filters dried for 48 hr at 60°C. Once dried, the filters and their contents were weighed and the filter pre-weight subtracted to obtain the total soil and organic matter accumulation. The bag was then cut open and the contents (approximately 100 g) removed and placed in crucibles. The crucibles and their contents were placed within a muffle furnace and the organic matter was determined in accordance with the method described by Nelson and Sommers (1982) with two exceptions. The first exception was the exclusion of the pretreatment, and the second was the temperature of the muffle furnace set at 500°C. It has been demonstrated these two exceptions do not significantly alter results (Chichester and Chaison, 1992).

Experimental Design and Analysis. Each cotton-based treatment was replicated three times in a completely randomized design. The control was replicated six times. Non-parametric analysis of variance Kruskal-Wallis (analysis of ranks) techniques were used to determine the statistically significant differences among the twelve treatments and Dunnett's multiple range test at the 95% confidence interval (SAS ver. 9.2, SAS Institute Inc., Cary, NC). The Kruskal-Wallis test was used due to heterogeneous variances in the data set. The reference control for the Dunnett's test was the commercial hydro-mulch used on slopes greater than 3:1. The response variables evaluated included total loss, soil loss, and mulch loss (represented as organic matter loss).

RESULTS AND DISCUSSION

Results showing the mean and standard deviation of total runoff, soil runoff, and organic matter runoff are presented in Table 2. Five treatments were not significantly different from the control in total runoff. The same five treatments were not significantly different from the control in soil runoff. Five treatments were not significantly different from the control in organic runoff. The intersection of the three sets of treatments not significantly different from the control includes treatments AG1, AG2 and CS1. The CS1 treatment was eliminated as the standard deviation of total runoff is greater than the mean total runoff indicating unreliability of performance. Remaining treatments AG1 and AG2 had mean total runoff of 96.2 and 64.7 kg/ha, respectively versus 26.5 kg/ha for the control. AG1 and AG2 were chosen for further research and development.

Table 2. Analysis of variance versus a control using Dunnett's Method.

Treatment[z]	Mean Total Runoff[y] (kg/ha)	Standard Deviation of Total Runoff	Total Runoff p-Value[x]	Mean Soil Runoff [y] (kg/ha)	Standard Deviation of Total Runoff	Soil Runoff p-Value[x]	Mean Organic Matter Runoff[y] (kg/ha)	Standard Deviation of Organic Matter Runoff	Organic Matter Runoff p-Value[x]
Control	26.5	13.1	1.0000	22.7	11.4	1.0000	3.9	1.8	1.0000
AG1	96.2	38.6	0.5114	56.3	29.8	0.5415	39.9	8.9	0.3132
AG2	64.7	10.6	0.9366	30.2	12.4	1.0000	34.6	1.8	0.7810
AG3	148.4	42.3	0.0639	67.3	31.2	0.1838	81.1	18.3	0.0010*
HG1	238.8	80.0	0.0012*	184.2	65.4	0.0004*	54.6	15.2	0.0604
AG4	181.6	7.1	0.0417*	131.6	12.4	0.0072*	50.0	5.4	0.1567
AG5	216.4	131.2	0.0033*	106.3	71.3	0.0238*	110.1	75.0	0.0008*
CS1	164.2	168.8	0.1123	120.6	122.9	0.0798	43.7	46.0	0.2720
HG2	153.0	51.0	0.1123	78.0	15.0	0.1735	75.0	36.1	0.0091*
AG6	199.0	45.6	0.0055*	92.7	31.2	0.0238*	106.3	18.1	<0.0001*
AG7	206.5	56.3	0.0145*	114.8	48.7	0.0277*	91.7	7.6	0.0014*
WG1	284.9	8.8	0.0007*	215.5	19.3	0.0005*	69.3	10.4	0.0145*

[z] Control = Commercial hydro-mulch product for use on slopes of 3:1 or greater. AG = Agricultural residue (same residue, seven different blends); HG = Haygrazer; CS = Cotton stalks; WG = Wheat straw.

[y] Total Runoff = Complete catch of soil and organic matter from trays. Soil Runoff = Total Runoff – Organic Matter Runoff. Organic Matter Runoff was determined by method described by Nelson and Sommers, 1982.

[x] p-Values below the 0.05 are significantly different from the control and denoted with an asterisk.

CONCLUSIONS

In an effort to efficiently evaluate the potential of utilizing the Cross-Linked Biofiber Process to incorporate low value biomass by-products into an effective hydraulic mulch blend, a research program was conducted between the USDA and Colorado State University. Biomass components included material derived from cotton, wheat, hay grazer and other agricultural residues. In addition, a popular commercially available hydro-mulch used on slopes of 3:1 or greater was used as a control. An analysis of the soil and organic content of runoff collected was conducted and blend constituents evaluated for their effectiveness in providing protection against rainfall induced soil erosion. Dunnett's multiple range and Kruskal-Wallis statistical tests were used to evaluate results and eliminate treatments not significantly different from the control. Three treatments were significantly different from the control. Treatment CS1 was eliminated from consideration as a result of large standard deviation in total runoff. The remaining two treatments, AG1 and AG2, were selected for further research and development based on their performance versus the control. Total runoff was 96.2 and 64.7 kg/ha for AG1 and AG2, respectively, versus 26.5 kg/ha for the control. This study demonstrates that agricultural by-products can be effectively used as rainfall erosion protection. In general, further investigation of waste products as erosion control measures is warranted. Specifically, the treatments showing the most promise in this study should be refined to provide an economically competitive product from agricultural by-products.

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DISCLAIMER

Mention of product or trade names does not constitute an endorsement by the USDA-ARS or Colorado State University over other comparable products. Products or trade names are listed for reference only. USDA is an equal opportunity provider and employer.

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