The *Journal of Cotton Science 17:302–308 (2013)*
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ENGINEERING AND GINNING

Hydromulch Blends Using Agricultural Byproducts: Performance Implications of Cotton Quantity

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ABSTRACT

Research has shown that hydromulch containing specific blends of cotton mixed with other agricultural byproducts is effective in providing protection from rainfall-induced erosion of soil surfaces prior to establishment of vegetation and in stimulating seed germination. To evaluate the effect of ingredient proportions on hydromulch blends incorporating low-value biomass byproducts, a cooperative research program was conducted between the U.S. Department of Agriculture and Colorado State University. Following construction of a rainfall test facility, 16 hydromulch blends (recipes) containing various quantities of identical components were tested under controlled rainfall intensities. Variations in biomass particle size, percent primary ingredient, percent polyacrylamide and percentage of other identical ingredients were systematically varied and tested as a hydromulch. Test plots consisted of sandy-loam and clay-loam soils. The soil and organic content of runoff was collected and recipes evaluated for their effectiveness in providing protection against rainfall-induced soil erosion. Standard errors and mean comparisons of total loss (soil and organic matter) and proportional soil loss were used to determine the best hydromulch recipe across both soil types. Two hydromulch recipes displayed promising results with lower total loss and more consistent results than the other recipes evaluated.

Human disturbances of the natural soil surface contribute greatly to siltation and sedimentation. Residential and commercial construction sites are known to be a disproportionally large contributor to sedimentation runoff issues. Due to the often necessary elimination of the natural vegetation and ground cover, the exposed, bare soil on construction sites can result in soil loss rates 10 to 20 times greater than that of agricultural lands (USEPA, 2000). In 2003, the federally mandated National Pollutant Discharge Elimination System (NPDES) Phase II program took effect requiring stormwater management plans for all activities disturbing more than 0.40 hectare (1 acre). In the effort to comply with regulations, construction activity erosion best-management practices (BMPs) have been 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. Beighley et al. (2010) studied multiple BMPs in a laboratory setting and their effectiveness in reducing sediment yield using construction-site installation techniques. Sediment yield reduction on a 2H:1V (horizontal:vertical, 50%) averaged 65% ranging from 20 to 95% depending on treatment applied. McLaughlin et al. (2009) reported similar improvement in reducing sediment yield in a field installation of check dams and polyacrylamide (PAM). Baker et al. (2012) evaluated compost/mulch effectiveness in reducing total suspended solids (TSS) and turbidity when applied to highway embankments and found reductions of 70% and greater. Application of surface mulch is a common, temporary BMP option that is utilized during the period between soil disturbance and revegetation. Straw, shredded paper, wood chips, and gravel have all been used widely for mulching (Agassi and Ben-Hur, 1992; Buchanan et al., 2002). Bhattarai et al. (2011) conducted laboratory and field experiments to determine the impact on effectiveness of combining erosion control methods. Results were promising, though mixed, depending on the slope tested. Conclusions suggested testing multiple types, ratios of mulches, and composts might yield improved efficiencies in sediment retention.

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The effectiveness of surface mulching has been well documented for many years. 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 sediment yield potential (Lattanzi et al., 1974; Mannering and Meyer, 1963). Mulch also reduces overland flow velocities once runoff occurs (Kramer and Meyer, 1969; Meyer et al., 1970, 1972).

In earlier cotton-based mulch studies (Holt et al., 2005a, b) hydromulch created from byproducts of the cotton ginning industry were evaluated at a relatively low slope (9%). For comparison, these were evaluated concurrently with wood and paper hydromulches commercially available from construction material vendors. The cotton-based products performance was equal to or better than wood and paper mulches in reducing soil loss during simulated rainfall. More recently Scholl et al. (2012) evaluated 11 different formulations of cotton-based hydromulch blends, produced using the Cross-Linked Biofiber Process (Holt et al. 2010), on a 2H:1V slope using sandy-loam soil. Testing was performed in conjunction with a popular commercially available wood-based hydromulch used on slopes of 3H:1V or greater. Scholl et al. (2012) revealed two agricultural residue/cotton-based hydromulch recipes that merited further research and development.

The purpose of this study was to further refine the agricultural residue/cotton-based hydromulch blends that performed well in the Scholl et al. (2012) study for later testing at a different facility under ASTM D6459-11: Standard test method for determination of rolled erosion control product (RECP) performance in protecting hillslopes from rainfall-induced erosion.

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, TX. The water supply to research facilities is furnished by Horsetooth Reservoir, which is adjacent to the ERC. Approximately 46 m^2 (500 ft^2) of the indoor portion of the Hydraulics Laboratory was dedicated to rainfall simulation, whereas soil preparation and hydromulch application were conducted in an auxiliary building and outside, respectively. Because this study was a follow-up to the Scholl et al. (2012) study involving refinement of the hydromulch blends, the refinement was carried out by systematically varying quantities of identical ingredients and documenting effects on rainfall-induced erosion. In addition, the study was replicated on sandy-loam and clay-loam soils to document soil-type influences on performance.

Cotton-based Hydromulch Blends. The 16 cotton-based hydromulch blends (recipes) evaluated contained some percentage of processed cotton gin byproducts (CGB), PAM, and processed sorghum stover. The treatment blends are listed in Table 1. All cotton byproducts and agricultural residues in the blends were processed through an attrition mill at CPPRU. The attrition mill (Reynolds Eng. & Equip. Inc., Muscatine, IA) created fibers from the materials instead of chopping or excessively reducing length. Once the cotton byproducts and agricultural fibers were processed, they were stored in a cool, dry location until shipped to CSU.

Table 1. Treatment/recipe blends evaluated[Z].

Recipe #	Sieve Size	Sorghum %	Cotton Byproduct %	PAM / Cot. Fiber %	Recipe #	Sieve Size	Sorghum %	Cotton Byproduct %	PAM / Cot. Fiber %	Recipe #	Sieve Size	Sorghum %	Cotton Byproduct %	PAM / Cot. Fiber %	Recipe #	Sieve Size	Sorghum %	Cotton Byproduct %	PAM / Cot. Fiber %
1	10	53	40.5	6.5	2	10	53	36.5	10.5	3	10	53	39	8	4	10	53	35	12
5	10	70	22	8	6	10	70	18	12	7	10	71	22.5	6.5	8	10	71	18.5	10.5
9	6	53	40.5	6.5	10	6	53	36.5	10.5	11	6	53	39	8	12	6	53	35	12
13	6	70	22	8	14	6	70	18	12	15	6	71	22.5	6.5	16	6	71	18.5	10.5

[Z] **The composition of each recipe evaluated including sieve size, percent sorghum fiber, percent cotton byproduct fiber, and percent polyacrylamide (PAM) and Cotton Fiber (Cot. Fiber). The PAM never exceeded 4% by weight in any recipe.**

Ninety-six soil plots were tested under simulated rainfall conditions in CSU's Hydraulics Laboratory. Experiments consisted of eight different formulations of ingredients where the sorghum stover and cotton materials had been processed over a six-mesh sieve (3.36 mm [0.132 in]) or 10-mesh sieve (2 mm [0.079 in]). To remove fine particles, sieving the agricultural residue and CGB was performed on the blended materials prior to the addition of PAM to the recipe. Experimental phases were soil plot preparation, hydromulch mixing and application, rainfall simulation and discharge collection, and sediment yield evaluation.

Soil Plot Preparation. Two soil types were used in this study, sandy loam and clay loam. Using the USDA soil classification system, the sandy loam consisted of 72% sand, 19% silt, and 9% clay and the clay loam consisted of 42% sand, 30% silt, and 28% clay. Prior to use, all soil was processed on a shaker table (sieved) with a 6.25-mm (0.25 in) screen size and stored in large, woven polypropylene sacks located in a climate controlled environment. Soil plots were contained in steel trays and measured 0.61 m (2 ft) wide by 3.05 m (10 ft) long and 7.6 cm (3 in) deep. Clean, dry trays were each filled with 186 kg (410 lb) of sandy loam or 175 kg (386 lb) of clay loam. Soils were wetted to their optimal moisture content, $10\pm2\%$ and $18\pm2\%$ for the sandy loam and clay loam, respectively, as determined by the Standard Proctor compaction test (ASTM, 2007). The soil surface was then leveled and compacted using a vibratory plate compactor and hand tampers. For all tests, sandy loam was compacted to an average bulk density of 1.43 g/cm^3 (89.0 lb/ft^3) with a standard error of 0.04 g/cm^3 (2.5 lb/ft^3) and clay loam was compacted to an average bulk density of 1.26 g/cm^3 (78.5 lb/ft^3) with a standard error of 0.05 g/cm^3 (3.4 lb/ft^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 hydromulcher and gantry system (Fig. 1).

Hydromulch Application. The hydromulcher used had a mixing tank capacity of 1,628 l (430 gal). Each run consisted of mixing 22.7 kg (50 lb) of a unique hydromulch blend using 302.8 l (80 gal) of water for a minimum of 10 min to ensure enough volume and time for proper mixing in the hydromulcher. Hydromulch was applied at 2,242 kg/ha (2,000 lb/acre). Uniformity was accomplished using an overhead gantry carrying the hydromulch applicator hose. For each unique hydromulch blend, the spray pattern width and the time to apply 75.7 l (20 gal) was determined. Using this information and a variable frequency drive controlled motor to control applicator hose speed on the gantry, uniform application rates were achieved. Once the hydromulch was applied, trays were moved into a climate-controlled environment and allowed to dry for 48 h prior to testing.

Figure 1. Hydromulcher with application gantry system in background (top) and gantry system applying uniform treatment application rate on soil tray (bottom).

Testing. Prior to rainfall simulation, three trays containing prepared soil plots were placed under the spray nozzle and elevated to a 2H:1V slope leaving the highest point of each tray approximately 3.96 m (13 ft) below the spray nozzle (Fig. 2). Rainfall simulation was performed using a stainless steel nozzle (Model ¾ WL-12 90, Bete Fog Nozzle, Inc., Greenfield, MA) that produced a conical spray pattern and manufacturer's estimated drop size of 563 µm at 1.30 kPa (27.1 psi). Uniform coverage of the soil plots was verified using the Christiansen Coefficient of Uniformity, (CU) (Christiansen, 1942) method and six graduated rain gages magnetically attached to each box (18 total graduated cylinders) containing the soil plots. The average CU for all tests was 91.2 with a standard error of 1.3. Using ASTM 6459 (ASTM, 2006) as a guide, where peak average rainfall intensity called for is 150 mm/h (5.91 in/h), measured test average rainfall intensity for this study was 145 mm/h (5.7 in/h). Filter bags capable of capturing 10-micron size particles were placed at the toe of each soil plot to filter all particles carried in runoff. The filter bags were labeled, dried, and pre-weighed prior to use. Video and time-lapse photography with a 1-min interval was initiated. Water pressure of approximately 1.44 kPa (30 psi) and flow rate of approximately 37.9 l/min (10 gal/min) were set and rainfall simulation began. All product recipe treatment tests were 45 min 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. Graduated rain gage 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, TX for soil and organic matter analyses.

Figure 2. Triplicate soil plot test configuration. Soil trays on soil cart elevated at 2H:1V.

Laboratory Analysis. At the CPPRU, the filter numbers were recorded and the filters dried for 48 h at 60 °C (140 °F). Once dried, the filters and their contents were weighed and the filter preweight subtracted to obtain the total soil and organic matter accumulation. The filters were 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

Table 2. Mean and standard errors of total loss rate (total loss [kg/ha]/rain intensity [cm/h]) and soil loss percent for the 16 agricultural byproduct hydromulch blends evaluated in this study for each soil type.

Recipe #	Mean Total Loss Rate ((kg/ha)/(cm/h))		Total Loss Rate Standard Error ((kg/ha)/(cm/h))		Mean Soil Loss (% of total)		Soil Loss Standard Error (% of total)	
	Sandy-Loam	Clay-Loam	Sandy-Loam	Clay-Loam	Sandy-Loam	Clay-Loam	Sandy-Loam	Clay-Loam
1	10.0	6.1	7.14	4.28	70.9	79.4	22.4	12.5
2	7.0	2.5	3.40	0.43	69.1	64.7	12.3	18.9
3	18.6	5.6	25.16	3.49	49.7	70.4	7.01	23.6
4	3.0	6.2	1.36	7.10	57.1	78.1	16.9	14.5
5	8.3	24.5	2.98	20.72	70.9	85.2	7.81	12.5
6	15.4	3.2	6.09	0.81	58.9	42.1	10.4	6.42
7	7.9	3.2	3.54	0.56	67.2	70.1	9.35	1.38
8	8.9	2.8	6.84	0.60	78.9	55.9	14.3	6.62
9	3.7	3.2	1.92	1.08	31.2	44.7	7.84	8.84
10	13.3	4.8	4.42	2.68	83.1	64.0	3.69	18.4
11	5.3	3.9	1.41	1.49	38.6	27.5	0.15	0.16
12	10.6	9.9	10.82	7.29	55.9	10.7	11.0	2.45
13	9.2	5.9	2.23	1.61	75.0	74.8	5.43	10.9
14	8.9	4.2	4.40	0.89	66.5	85.6	22.6	0.83
15	5.9	4.4	0.67	0.91	35.7	50.0	10.9	13.9
16	7.9	3.7	1.01	0.20	70.8	52.1	2.02	9.02

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 was set at 500 °C (932 °F). 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 with soil type as a random factor. Sixteen hydromulch blends were each applied to clay-loam and sandy-loam soil plots and placed on the soil plot test cart (Fig. 2). Mean and standard errors of soil loss proportion and total loss (organic matter and soil) were analyzed compared to the overall means of the treatments evaluated with the intent on selecting the top recipe(s) for field testing versus a popular conventional wood-based hydromulch. The total loss data (kg/ha) were standardized according to rain intensity (cm/h) to produce total loss rate. Total loss rate data were transformed using natural log to account for skewness. Soil loss proportion was defined as the ratio of soil loss to total material loss (soil plus organic matter).

RESULTS AND DISCUSSION

Table 2 shows the mean and standard errors for Total Loss Rate (total loss [kg/ha]/rain intensity [cm/h]) and Soil Loss Proportion (percent of total loss) by hydromulch recipe. Figures 3 (Mean Total Loss Rate) and 4 (Mean Soil Loss Proportion) show the plots of the mean and standard error for all 16 recipes evaluated for both clay-loam and sandy-loam soil types. Figure 3 shows all recipes except 5, 12, and 13 performed better than the testing mean for Total Loss Rate for at least one soil. Figure 4 shows the proportion of the total loss that was attributed to soil. The recipes that were equal to and/or less than the overall soil loss proportion mean for one soil type for the treatments evaluated were recipes 3, 4, 6, 8, 9, 11, 12, 15, and 16.

From the 16 recipes evaluated, there were eight recipes (3, 4, 6, 8, 9, 11, 15, and 16) that showed potential and warranted further investigation based on the metrics of Total Loss Rate and Soil Loss Proportion. However, some of the recipes exhibited varying performance from one metric to the other. For example, Recipe 3 has means and standard errors that were below average for Soil Loss Proportion on the sandy loam, but Recipe 3 was above the mean for Soil Loss Proportion on clay loam. It was also highly variable in its performance as exhibited by its soil loss proportion standard error for the clay loam. Another example was Recipe 12, which exhibited desirable performance for Soil Loss Proportion on clay loam for both overall mean and standard error, and performed better than the overall mean on the sandy loam but had a standard error that exceeded the mean. However, Recipe 12 performed worse than the mean and standard error on both soil types when evaluated for Total Loss Rate.

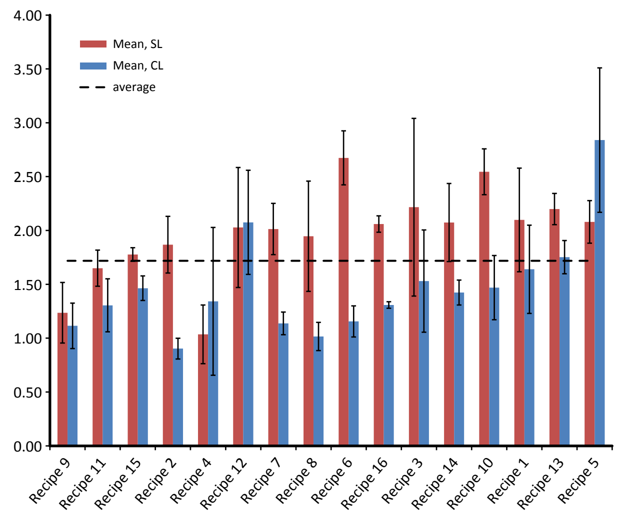

Figure 3. Mean and standard error of the total loss rate (Ln [total loss (kg/ha)/rain intensity (cm/h)]) for each of the 16 hydromulch recipes evaluated on clay-loam (CL) and sandy-loam (SL) soils. Dashed line represents the overall mean (Ln) from the 16 recipes.

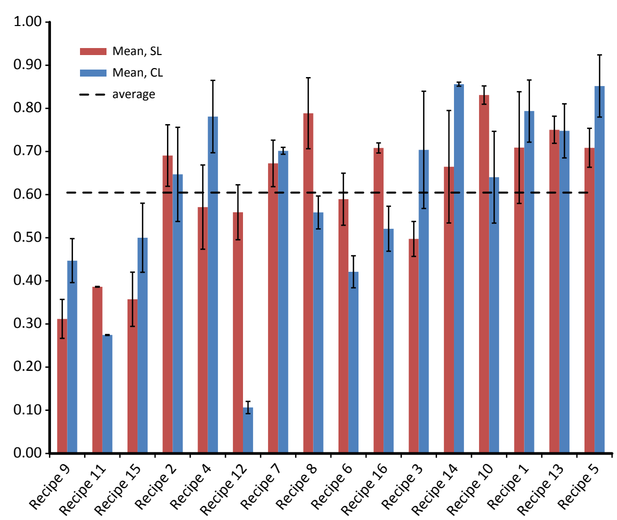

Figure 4. Mean and standard error of soil loss proportion (soil loss/total loss) for each of the 16 hydromulch recipes evaluated on clay-loam (CL) and sandy-loam (SL) soils. Dashed line represents the overall mean from the 16 recipes.

Three recipes had promising results, 9, 11, and 15, on both soil types for the Total Loss Rate metric evaluation. Recipe 9 outperformed both Recipe 11 and 15 when evaluating Total Loss Rate means and performed comparably in variability when measured using standard error. Recipe 15 had a slightly higher Total Loss Rate than Recipe 11 but a slightly lower standard error. All three recipes performed better than the overall Total Loss Rate mean and the mean of the standard error on both soils. Only two recipes had promising results when Soil Loss Proportion was evaluated: Recipe 9 and Recipe 11. Recipes 9 and 11 were the only recipes to perform better than the overall Soil Loss Proportion mean and standard error on both the sandy loam and clay loam. The remaining recipes, when evaluated for Total Loss Rate and Soil Loss Proportion, did not perform as well as Recipes 9 or 11 due to less than desirable performance as a result of: 1) too much variability with a given metric, 2) high soil or total loss, and/or 3) variability based on soil type.

Table 2 shows high variability for three recipes: 3 (sandy loam and clay loam), 5 (clay loam), and 12 (sandy loam and clay loam). Even though there were other recipes with large variability, these three treatments had noticeable variability during testing. Both Recipes 3 and 12 had large variability due to mulch failures on one or two of the runs where the hydromulch loss (i.e., organic matter loss) was greater than the soil loss, resulting in substantial total loss numbers. Even though large variability for a given recipe blend could occur due to poor mixing of the PAM or uneven application of the mulch, none of these situations were noted for any of the treatment blends evaluated. Unlike Recipes 3 and 12, Recipe 5 (clay loam) had single rill formations in two runs that caused excessive soil loss. For the runs with large variability in Recipe 5, the organic matter loss was less than 10% of the total loss. To put this in perspective, the average organic matter loss across all runs for the 16 treatments was 34% of the average total loss.

SUMMARY AND CONCLUSIONS

This study was conducted as part of a research program between the USDA and Colorado State University. The objective of this study was to refine the cotton-based hydromulch blends (recipes) that were most effective in Scholl et al. (2012). Sixteen blends were evaluated with eight of the 16 blends differing only in the size of fine particles removed, six-mesh sieve (3.36 mm [0.132 in]) or 10-mesh sieve (2 mm [0.079 in]). Other than the size of fine particles removed, the difference in blends was ratios of processed agricultural fibers (sorghum stover, cotton carpel, cotton fiber) and PAM. The percentage of PAM in the blends never exceeded 4%. The 16 hydromulch recipes were each evaluated on a sandy-loam and clay-loam soil. An analysis of the soil and organic content (total loss) collected was conducted and evaluated versus the overall mean for all blends on both soil types. Blend constituents (recipes) were evaluated for their effectiveness in providing protection against rainfall-induced soil erosion. Eight recipes had desirable mean responses that were equal to or better than the overall mean. Six of the eight recipes were eliminated from consideration as a result of: 1) too much variability, 2) high soil or total loss, and/or 3) performance variability based on soil type. The two treatments that had desirable performance were Recipes 9 and 11. Recipe 11 had low mean total loss rate and standard error for both clay and sandy loams and low mean soil loss proportion and standard error for sandy loam and clay loam. The blend for Recipe 11 consisted of: fines less than six-mesh sieve (3.36 mm [0.132 in]) removed, 53% fiberized sorghum stover, 39% fiberized cotton byproducts, and 8% cotton fiber and PAM. Excellent performance was also seen in Recipe 9, which had below average mean values and small variability for both the total and soil loss metrics. Recipe 9's composition was: fines less than six-mesh sieve (3.36 mm [0.132 in]) removed, 53% fiberized sorghum stover, 40.5% fiberized cotton byproducts, and 6.5% cotton fiber and PAM.

This study revealed a desirable blend of agricultural byproducts, comprised of approximately 40% cotton byproducts, for further field evaluation versus a commercially popular wood-based hydromulch commonly used on slopes of 3H:1V or greater. Results also indicate two recipes that could prove viable, but further study is needed to validate findings presented in this report. One or both recipes will be sent for rainfall testing under ASTM protocol. The decision will be made by the manufacturer, most likely based on material cost at the time of testing.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of Landmark Earth Solutions, Incorporated, specifically, Bart Daniel, for his support.

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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