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ENGINEERING AND GINNING

Comparison of Cotton-based Hydro-mulches and Conventional Wood and Paper Hydro-mulches – Study II

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ABSTRACT

The erosion of soil from steep slopes, bare soil, or construction sites can create gullies that adversely impact fish and wildlife in the surrounding environment and limit the ability of vegetation to become established. Mulches have been one means of mitigating the effects of erosion. Mulches that are commonly applied to disturbed soil or steep slopes with a hydro-mulcher are commonly known as hydro-mulches and are most often made from wood and paper. In this study, conventional wood and paper hydro-mulches were compared with cottonseed hulls and three types of processed cotton gin by-products. The mulches were applied at two rates, 2241 and 3362 kg/ha (2000 and 3000 lb/a). An unconsolidated sandy clay loam soil on a 9% slope was subjected to a 10.41-cm/h (4.1-in/h) rain event. The response variables investigated were mulch loss (as percentage of applied), soil loss, and mulch coverage factor (C-Factor). The initial C-Factors for the cotton-based mulches were lower than the wood or paper mulches, but the cotton-based mulches performed equal to or better than the conventional wood and paper mulches in reducing soil erosion. Overall, the cotton-based mulches showed promise in erosion control applications, but refinement of the product is needed in order to produce a hydro-mulch that provides soil coverage equal to conventional wood hydro-mulches.

Erosion due to rainfall from sites with steep slopes, bare soil, or construction activity can create problems, such as on-site gully formation and off-site non-point source pollution (Flanagan et al., 2002a; 2002b). To mitigate the effects of erosion due to rainfall, mulches are often applied to minimize soil erosion until vegetative or permanent cover is established (Buchanan et al., 2002). Organic mulches are typically made from plant residues or plant by-products that are commonly viewed as waste products. Wheat straw, waste paper, pine needles, and wood chips, referred to as traditional mulches, have all been widely used because of their availability and affordability, but other organic wastes could be processed to create mulches that perform equal to or better than traditional mulches. In geographic locations where previously underutilized organic wastes are produced in excessive quantities, a potential economic advantage could exist in using these wastes as a raw material in the production of high quality mulches.

In an earlier study (Holt et al., 2004), mulches created from by-products of the cotton ginning industry were evaluated. These mulches were produced using the COBY Process described by Holt and Laird (2002). In the initial study, the mulches were applied to the soil by hand, and then water was applied to the mulch and soil in an effort to simulate the moisture that would exist in the soil if the mulches had been applied with a hydro-mulcher. The primary reason for hand applying the mulches was to ensure the desired application rates were achieved, but some of the mulch treatments did not cover the soil surface area as well as when mulches are applied with a hydro-mulcher.

The purpose of this study was to evaluate six of the same mulches evaluated in the initial study using a hydro-mulcher. Other variations between this study and the initial study include increasing the application rates from 1121 and 2241 kg/ha (1000 and 2000 lb/a) to 2241 and 3362 kg/ha (2000 and 3000 lb/a) and increasing the rainfall intensity from 6.35 cm/h to 10.41 cm/h (2.5 in/h to 4.1 in/h). The increased application rates were more in-line with conventional application rates used in the industry.

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The rainfall was increased to test the mulches at a rainfall amount equivalent to other areas in Texas, such as Temple, that experience higher rainfall. The 100-year rain for Temple, Texas, is approximately 10.41 cm/h (4.1 in/h) (Hershfield, 1961). The objective of this study was to evaluate the performance of cottonseed hulls and COBY mulches applied with a hydro-mulcher for use in erosion control and vegetation re-establishment applications by comparing these mulches with conventional wood and paper hydro-mulches.

MATERIALS AND METHODS

Mulch products. Six products, including cottonseed hulls, commercially available wood and paper hydro-mulches, and three COBY products, were evaluated in this study. The cottonseed hulls, wood hydro-mulch, and paper hydro-mulch were purchased from commercial vendors and were evaluated as commercial, ready-to-use products.

The three COBY products were composed of different base products and were identified by dying the products yellow, green, and red. The base material, gin waste, used in producing the COBY Yellow was obtained from a commercial cotton gin in Arizona that processes picker-harvested cotton. COBY Green was produced using gin waste from a commercial West Texas cotton gin that processes stripper-harvested cotton that is primarily (>90%) field cleaned (i.e. less burs in the waste). The COBY Green gin waste was ground using a tub grinder prior to the COBY process. Both the Arizona and West Texas gin waste did not include motes (i.e. lint cleaner waste). COBY Red was manufactured using gin waste produced by a commercial size cotton gin at the USDA-ARS Cotton Production and Processing Research Unit (CPPRU) in Lubbock, Texas. The gin waste used in producing the COBY Red corresponded to stripper-harvested cotton that was field cleaned. The COBY Red base material included lint cleaner waste.

Each of the COBY products was produced using the COBY Process at the USDA-ARS, CPPRU in Lubbock, Texas. A more in-depth discussion of the COBY process has been provided in Holt et al. (2004). Figure 1 shows a schematic of the process used in manufacturing the COBY products. Sieve analysis was used to determine the size and consistency of the three commercial and three COBY products.

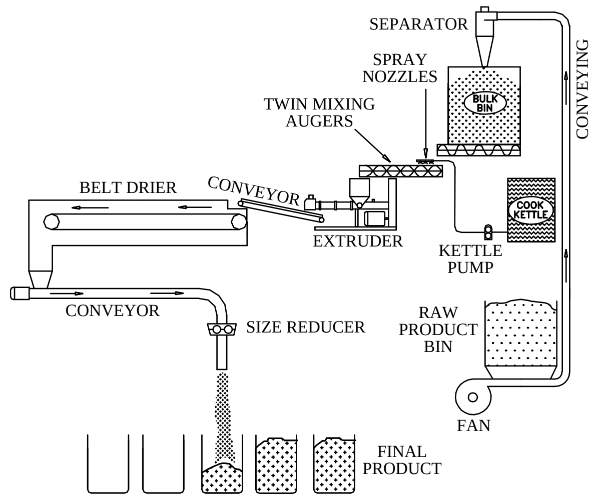

Figure 1. Schematic of the process used to produce the COBY mulch.

Experimental setup and treatment application. The erosion study was conducted at the USDA-ARS, CPPRU in Lubbock, Texas, using a sandy clay loam consisting of 20% clay, 17% silt, and 63% sand. Prior to conducting the test, the soil was conditioned using a shaker table (sieve) to break-up and remove clods and increase soil uniformity. The size of the shaker table screen was 0.635 cm^2 (0.25 in^2). After the soil was conditioned, it was loaded into nylon tote bags and stored in a dry location for later use.

In addition to mulch type, application at 2241 and 3362 kg/ha (2000 and 3000 lb/a) was evaluated. In order to determine the required hydro-mulch pump motor throttle setting and application time per unit area for the two application rates, calibration spray tests were conducted prior to the study. The calibration tests were performed using the same mulches, water/mulch mixing ratios, and application rates to be evaluated. The calibration process consisted of applying the various mulches over a known area at various pump speeds and application times. During evaluation, the amount of mulch applied, throttle position (pump motor speed), and application time were measured and recorded. The pump speed required for the mulches evaluated in this study was 2400 rpm with slight adjustments in application time depending on the mulch type and application rate.

The day before applying mulch, 9 to 12 trays were each loaded with approximately 195 kg (430 lb) of soil. The soil trays were designed to hold a volume of 0.143 m^3 (5 ft^3). The dimensions of each tray were 0.61-m (2-ft) wide by 3.05-m (10-ft) long. Soil sampled from dryland and irrigated cotton fields with similar textured soil in four counties near Lubbock were reported to have average bulk densities of 1.4 Mg/m^3 (87.4 lb/ ft^3) in the top 15 cm of soil surface (Bronson et al., 2004), so the soil in each tray was packed and leveled to obtain the same density.

After packing and leveling the soil, a 2:1 ratio of water to mulch was mixed in the hydro-mulcher tank (Fig. 2). The mulch slurry was mixed using the mechanical agitator running through the center of the mix tank. After mixing, the throttle of the hydro-mulcher's pump motor was set to 2400 rpm, and the mulch was applied to the soil in the erosion trays. Mulch was applied at 2241 or 3362 kg/ha (2000 or 3000 lb/a). No surfactants or polyacrylamides were applied to the mulches before or during application.

Figure 2. The hydro-mulcher used for this study.

After applying the mulch, the trays were stored in a covered area for a minimum of 16 h before initiating the rain event. Prior to the rain event, digital pictures were taken at two predetermined 0.37 m^2 (4 ft^2) sections at the front and back of each tray being evaluated that day. The digital pictures were taken in an enclosed building using consistent lighting and were used to measure mulch coverage. During each rain event, three trays were loaded onto a cart that was wheeled into the rain simulator. Once the cart was in position under the spray nozzle, the end of each tray was elevated using a hand winch so that the tray had a 9% downward slope from the back to the front of the tray. The slope of each tray was verified using an Empire Magnetic Protractor (Northern Tool and Equipment; Burnsville, MN). The highest point of each tray was approximately 3.96 m (13 ft) below the spray nozzle. The spray nozzle used was a 1/2-HH-Brass-50W, wide angle/square spray nozzle (Spraying Systems Company; Wheaton, IL). After adjusting the tray slope, barrels were placed on scales located under the flume of each tray to catch the soil and water runoff. Once all equipment was set-up and initialized, the rain simulation was started. The rain simulation nozzle was connected to a main water supply through a Recordall flow meter (Badger Meter, Inc.; Milwaukee, WI) and pressure gauge, which were monitored to maintain a constant pressure and flow rate to the nozzle. The simulated rain event corresponded to 10.41 cm/h (4.1 in/h) of rain. Figure 3 shows three trays in the rain simulator.

Figure 3. The erosion trays in the rain simulator.

Once the rain event was initiated, the data collection procedure was used as follows: 1) record rain simulation start time; 2) activate scale data loggers to record (5 s intervals) the amount of runoff collected in the barrels under each tray's flume; 3) record the time between the start of the rain event and the start of runoff for each tray; 4) once runoff began, grab samples were collected every 5 min for 30 min, in pre-weighed glass jars; 5) after 30 min of runoff for a given tray, the scale data logger was stopped and the collection barrel removed from the scale; 6) the rain simulation continued until all three trays had experienced 30 min of runoff. The 30 min of runoff was used instead of a set time period, because the testing was intended to evaluate the effectiveness of the various mulches at reducing erosion while experiencing water flow, not to determine their absorptive properties. The time-to-runoff was recorded as a matter of procedure and not as a response variable to be analyzed.

Upon completing the rain event, the trays were lowered to a horizontal position and digital pictures were taken of the same areas photographed prior to the rain simulation. These digital pictures were used in evaluating the amount of mulch that was eroded due to the rain event. This procedure was repeated for all 36 runs.

The grab samples collected during the rain simulation were weighed and then oven dried at a temperature of 82.2°C (180°F) for 48 h. After 48 h, the grab sample jars were removed from the oven and re-weighed. The dried material in each jar was removed and placed in plastic bags and sent for organic matter analysis (i.e. mulch and/or grass seed). The organic matter analysis was performed 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 was set at 500 °C (932 °F).

Image analysis. The coverage images obtained prior to the rain events were analyzed using Paint Shop Pro 9 software (Corel Minneapolis; Eden Prairie, MN). The images were analyzed by digitally removing the soil from each picture and converting the image to a negative (i.e. black and white image) in which the white area represented the visible mulch. After the conversion process, the histogram function was used to determine the percentage of pixels that were white and black (i.e. mulch or soil). The percentage of white pixels determined by the histogram function corresponds to the mulch coverage factor (C-Factor). The lighting was held constant while taking the images to reduce quality and color variability. Variation in mulch color did not prohibit the pixel analysis, but did result in some images taking a greater amount of time to analyze. The C-Factor assigned to each run was based on the average coverage factor for the front and back images of each tray.

Experimental design and data collection. This study was set-up as a randomized complete block design with treatments blocked by day. Each treatment was replicated three times. Standard analysis of variance techniques were used to determine the statistically significant differences among the twelve treatments by the Ryan-Einot-Gaberiel-Welsch multiple range test at the 95% confidence interval (release 8.02; SAS Institute Inc., Cary, NC). The response variables evaluated from the data included mulch loss (as a percentage of applied), sediment loading of runoff, soil content of the runoff, and mulch coverage factor (C-Factor).

RESULTS AND DISCUSSION

Results of the sieve analysis, based on three measurements, are reported in Table 1.

The results of two response variables measured, sediment loss and percentage of soil contained in the runoff, for the mulches are shown in Table 2. Sediment loss (P = 0.001) and the percentage of soil in runoff ($P < 0.001$) were significantly different for mulch type. The response variables analyzed in this study were selected because they are important in determining the perceived and actual benefits of erosion control mulches. Even though other factors influence the perception and performance of mulches, measured soil loss is one of the most common measures used

Table 1. Average percentages of mulch remaining on each sieve from three replicated analyses of each mulch

Sieve size [mm (in)]	Percentage of mulch remaining on sieve					
	COBY green	COBY red	COBY yellow	Hulls	Paper	Wood
15.8 (5/8)	1.97	26.67	24.74	0.00	24.27	2.23
9.5 (3/8)	33.05	41.02	37.02	0.00	11.67	1.40
7.9 (5/16)	6.46	3.11	3.05	0.00	3.76	0.37
4.76 (3/16)	29.21	17.36	20.49	8.54	12.79	0.56
1.95 (1/13)	17.23	7.86	9.79	71.63	24.08	4.57
1.41 (1/18)	3.18	0.97	1.49	9.19	6.11	5.31
0.79 (1/32)	3.56	0.97	1.38	3.12	4.80	20.11
0.18 (1/140)	3.84	1.46	1.11	3.86	9.97	44.22
0.08 (1/318)	1.12	0.49	0.55	2.84	2.16	14.34
0	0.38	0.10	0.37	0.83	0.38	6.89

to evaluate mulch performance. Sediment losses during 30 min runoffs are presented in Mg/ha (ton/a). Although the sediment loss values appear extreme, this data is based on a 9% slope with an unconsolidated soil that has been subjected to 10.41 cm/h (4.1 in/h) of rainfall with 30 min of water flow over the surface. Erosion rates can be extremely high for bare soils under similar conditions. The data presented in Table 2 shows that the soil losses associated with using the paper mulch are significantly higher than losses associated with using any of the cotton-based mulches. COBY Red, Green, and Yellow, hulls, and wood were not statistically different for sediment loss. Paper mulches exhibited the greatest loss of 27.17 Mg/ha (12.12 ton/a). The lowest sediment loss occurred with the COBY Red mulch (8.52 Mg/ha [3.80 ton/a]), followed by the cottonseed hulls (11.37 Mg/ha [5.07 ton/a]). The paper mulch had significantly more soil (10.54%) in the total runoff collected than any of the cotton based mulches. COBY Red had significantly less soil (3.57%) in the total catch than both paper and wood mulches.

Table 2. Mean sediment loss and percentage of soil in runoff for each of the mulches evaluated

Mulch	Sediment loss [Mg/ha (ton/a)][x]	Soil in runoff (%)[y]
COBY green	12.76 (5.69) b[z]	5.11 bc
COBY red	8.52 (3.80) b	3.57 c
COBY yellow	14.66 (6.54) b	6.34 bc
Hulls	11.37 (5.07) b	4.69 bc
Paper	27.17 (12.12) a	10.54 a
Wood	18.97 (8.46) ab	7.67 ab

[x] Amount of sediment loss for the erosion tray after 30 min of runoff from a 10.41-cm/h (4.1-in/h) rain event.

[y] The percentage of soil in the runoff from the rain event.

[z] Means within a column followed by the same letters are not significantly different at the 95% confidence limit according to Ryan-Einot-Gaberiel-Welsch multiple range test.

The results for sediment loss and soil content of the runoff for the two application rates are shown in Table 3. The responses were significantly different between application rates ($P < 0.003$). The sediment loss and percentage of soil in runoff were greater for the lower application rate (2241 kg/ha [2000 lb/a]). The higher sediment loss and percentage of soil in runoff for the lower application rate was not surprising, since less mulch on the soil surface to hold the soil in place would logically result in greater soil runoff.

Table 3. Mean sediment loss and percentage of soil in runoff for each application rate

Application rate [kg/ha (lb/a)]	Sediment loss [Mg/ha (ton/a)][x]	Total soil (%)[y]
2241 (2000)	19.3 (8.6) a[z]	7.7 a
3362 (3000)	11.9 (5.3) b	4.9 b

[x] Amount of sediment loss for the erosion tray after 30 min of runoff from a 10.41- cm/h (4.1-in/h) rain event.

[y] The percentage of soil in the runoff from the rain event.

[z] Means within a column followed by the same letters are not significantly different at the 95% confidence limit according to Ryan-Einot-Gaberiel-Welsch multiple range test.

The percentage of mulch loss during the simulated rain event is shown in Figure 4. Mulch loss was significantly different among mulch types (P = 0.004), between application rates ($P < 0.001$), and for the interaction between mulch and application rate (P = 0.017). The highest percentage of mulch loss over the entire rain simulation for an application rate of 2241kg/ha (2000 lb/a) was 7.8 % with wood and the highest percentage loss for an application rate of 3362 kg/ha (3000 lb/a) was 5.4% with paper. The lowest percentage of mulch loss for the 2241kg/ha (2000 lb/a) rate occurred with cottonseed hulls (1.6%), while COBY Red had the lowest percentage of mulch loss (1%) at the higher application rate. For the lower application rate, the COBY mulches lost around 5% soil, which decreased to about 2% at the higher rate of 3362 kg/ha (3000 lb/a). Paper mulch loss between application rates was 5.5 and 5.4% for the 2241 (2000) and 3362 kg/ha (3000 lb/ac) rates, respectively.

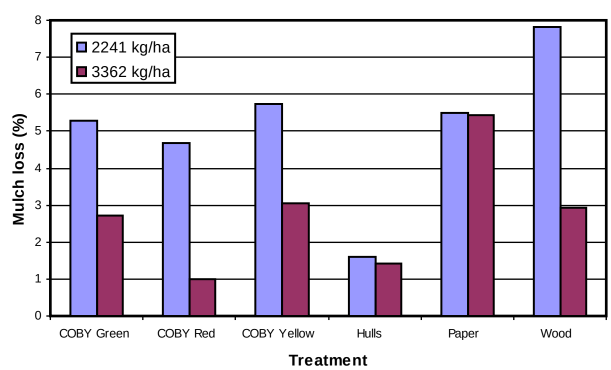

Figure 4. Average percentage of mulch, organic material lost due to runoff during the simulated rain event for the two application rates and six mulches evaluated in this study.

The average soil coverage (C-Factor) for each mulch at the two application rates is shown in Figure 5. C-Factor was significantly different among mulch types ($P < 0.0001$), between application rates ($P < 0.0001$), and for the mulch by rate interaction ($P < 0.0001$). The C-Factor for wood and paper ranged from 57 to 96% depending on the mulch and application rate applied. The overall appearance of the wood and paper mulches was appealing to the eye and the green color of both mulches contrasted well with the red color of the soil. Unlike the wood and paper mulches, the cotton-based mulches produced lower coverage factors, even though the same quantity of material was applied. The C-Factor ranged from 10 to 28% for all the cotton-based mulches with differences among mulches and between application rates. Of the cotton-based mulches, cottonseed hulls had the highest C-Factors (21 and 28%), and COBY Green had the lowest (10 to 12%) C-Factors. The low C-Factor rating for the cotton-based mulches was apparent from visual observation made after applying the mulches. At first, it was believed that the material was not being applied due to "dewatering" and was still in the hydro-mulcher's tank, but the amount of mulch remaining in the tank appeared to be the same as that of the wood and paper mulches. Dewatering occurs when the mulch does not stay evenly mixed in solution and the water is applied, but a majority of the mulch floats at the top of the slurry mix. A second theory was that the mulch became buried in the soil during application. This theory was validated when the top layer of soil was removed 25 to 30 min after starting the rain event, and the buried mulch was revealed.

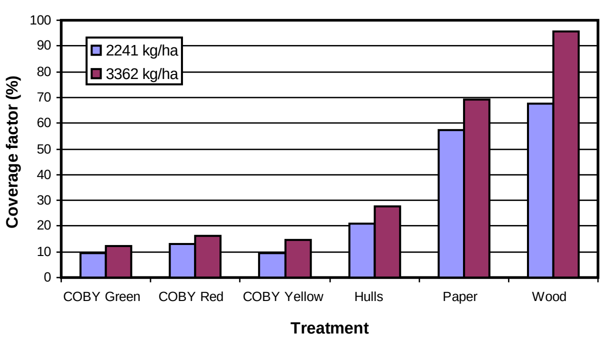

Figure 5. Average percentage of soil covered by mulch [coverage factor (C-Factor)] for the six mulches and two application rates prior to the rain event.

The digital images taken of the cotton-based mulches after the rain event were analyzed using the same procedures as with the initial pictures before the rain event. The results showed, on average, a two-fold increase in C-Factor ratings for the COBY mulches after the rain event compared with the C-Factors measured before the rain event. For cottonseed hulls there was a 1% increase in C-Factor at the 2241 kg/ha application rate, but a 20% reduction at the 3362 kg/ha rate. The individual particles of the cottonseed hulls mulch were more consistent in size than any of the other mulches (Table 1). The consistency in size coupled with the fact that the hulls did not have any "fibrous" components longer than 4.76 mm (3/16 in), resulted in less "spreading out" of the hulls on the soil than the other mulches. The appearance of the hulls on the soil was the same as they were before they were put into the hydro-mulcher's mix tank, resulting in lower C-Factor ratings. Besides becoming imbedded into the soil during application, the lint portion of the COBY mulches "spider webbed" on the soil, but in doing so the lint almost disappeared and was not as visually noticeable unless clustered with a bur, stick, or leaf fragment. If the COBY mulches were not buried during application, they would have had at least twice the coverage reported in Figure 5. Even with twice the coverage, the COBY mulches would have had C-Factors that were 30 to 50% lower than the wood and paper mulches, which is not sufficient for commercial use. Given the performance of the cotton-based mulches, improvements and/or changes in processing to enhance the C-Factor of the mulch need to be investigated.

SUMMARY AND CONCLUSIONS

This research was a follow up study of an evaluation of cotton-based mulches produced from cottonseed hulls, west Texas gin waste, Arizona gin waste, and tub-ground west Texas gin waste (Holt et al., 2004). The gin waste used in this study was processed using the COBY Process (Holt and Laird, 2002). This study looked at the effectiveness of these "cotton-based" mulches compared with conventional wood and paper mulches commonly applied by hydro-mulch\hydro-seeding units for controlling erosion and promoting the establishment of vegetation. The erosion testing was performed at USDA-ARS, Cotton Production and Processing Research Unit in Lubbock, TX. An unconsolidated sandy clay loam soil on a 9% slope was used in the study. The soil test plots were subjected to a 10.41-cm/h (4.1-in/h) simulated rain event. Mulch loss (as a percentage of applied), sediment loading of runoff, soil content of the runoff, and mulch coverage factor were evaluated. Overall, the cotton-based mulches (COBY and cottonseed hulls) performed equal to or better than the conventional wood and paper hydro-mulches in regards to reducing soil erosion, but improvements in processing are needed in order to improve the visual appearance of the cotton-based mulches once they have been applied to the soil (soil coverage). The cotton-based mulches tended to get buried in the soil during application, resulting in coverage factors that were 40 to 85% lower than wood or paper hydro-mulches. Although the C-Factor for the cotton-based products was lower than the traditional hydro-mulch products, the erosion control properties indicate a promising potential for use of by-products from cotton industries in erosion control applications. Additional studies are planned to refine and evaluate other means of processing raw materials from cotton-based industries for use in Green Industry applications.

DISCLAIMER

Mention of product or trade names does not constitute an endorsement by the USDA-ARS over other comparable products. Products or trade names are listed for reference only.

ACKNOWLEDGEMENTS

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