Combining cottage cheese whey and straw reduces erosion while increasing infiltration in furrow irrigation

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Interpretive summary

Calcareous silt loam soils are very susceptible to erosion when furrow irrigated. Placing loose straw, cottage cheese whey or cottage cheese and whey in the irrigation furrow dramatically reduces soil movement in the furrow. Straw or whey alone reduced soil loss by 60 to 85 percent and whey combined with straw reduced soil loss by 96 to 98 percent. These treatments also increased water intake rates by 50 to 60 percent. Straw and whey are often agricultural byproducts or wastes than may be used to solve an environmental problem.

Key words: byproduct utilization, irrigation runoff, mulching, sediment, sediment reduction, sediment retention, soil conservation, water quality.

ABSTRACT: Loose straw in irrigation furrows can decrease irrigation induced erosion, and acid cottage cheese whey can increase soil aggregate stability and soil infiltration. A field study was conducted at two sites where these materials were compared alone and in combination to determine their effectiveness in increasing infiltration and reducing irrigation induced erosion. Straw was applied by hand and whey was applied by gravity flow down irrigation furrows, 76 cm apart, and the field was planted to sweet corn (Zea Mays L.). Straw + whey was the most effective treatment for controlling erosion and sediment loss. Seasonal infiltration was significantly higher for straw + whey than for other treatments at the first site, and all three treatments increased infiltration over that of the control at the second site. These studies showed that two inexpensive agricultural byproducts, cottage cheese whey and straw, applied to irrigation furrows of different slopes can significantly reduce soil loss and increase infiltration.

Cottage cheese whey production in the United States exceeded 370,000 metric tons during 1990-1991 (U.S. Crop Reporting Board 1992). Approximately nine metric tons of whey results from the production of each metric ton of cottage cheese. The whey from cottage cheese and creamed cheese made by the phosphoric acid method is referred to as acid whey, and it is an excellent animal feed, but the supply of whey exceeds the demand for animal feed in some areas thereby creating a disposal problem. The acid whey cannot be economically dehydrated as is possible for sweet whey derived from cultured cheese production. Disposal through sewage plants is very expensive because whey has a high chemical oxygen demand (COD). Land application is an alternative, less expensive disposal method that can be beneficial, particularly where the whey can be applied to sodic soils. Research has shown that cottage cheese whey can speed sodic soil reclamation by improving soil chemical and physical conditions (Jones et al. 1993; Lehrsch et al. 1994; Robbins and Lehrsch 1992). Those studies show whey increased aggregate stability and decreased soil dispersion, indicating that acid whey might decrease soil erodibility, and be useful for controlling irrigation induced erosion.

Irrigation induced erosion is a serious problem in many irrigated areas of the western United States (Brown et al. 1974). The severity of irrigation induced erosion is determined by stream size, slope, aggregate stability, cleanliness of irrigation water, furrow roughness, and plant residue (Brown et al. 1988). Berg and Carter found that as furrow slopes exceeded 1%, erosion increased sharply on row-cropped fields. For example, sediment loss from a sugarbeet field with a 4% slope was 141 mt/ha over a single season.

Crop residues on and in the soil surface can reduce soil erosion (Lehrsch et al. 1994). Research has shown that corn residue in irrigation furrows decreases erosion and increases infiltration (Aarstad and Miller 1978), and that small amounts of cereal straw placed in furrows effectively reduces erosion (Brown 1985a. b; Miller and Aarstad 1971). Loose straw in furrows of a dry bean field reduced net sediment yields by 52% at a flow rate of 13 l/min. and 71% at 16 l/min. (Brown 1985a). Infiltration was increased as much as 50% in these studies.

When acid whey was placed on lysimeter soil columns to reclaim sodic soils, aggregate stability increased (Jones et al. 1993; Lehrsch et al. 1994). The acid whey dissolved lime and released Ca into the soil solution. This Ca replaced Na on the soil exchange complex and helped flocculate clay particles. The Ca and PO4 ions from the phosphoric acid used to process the cottage cheese also precipitated helping to cement the newly formed aggregates resulting from the flocculation process. Milk proteins in the whey are sticky and may also help aggregates form. Whey contains milk sugars and proteins that stimulate soil biological activity which produces polysaccharides, that can act as cementing agents. These processes along with high Ca and K concentrations in the acid whey, promote soil aggregate stability (Lehrsch et al. 1994). A 1991 preliminary study showed that cottage cheese whey decreased furrow erosion by causing loose organic material to adhere to furrow walls. The organic material was still in place after several 8-hour irrigations. Because of earlier success in controlling erosion with straw, and with the potential that whey might also be beneficial in preventing soil detachment, whey was combined with straw to determine the effect on erosion and infiltration on 2.3%, 2.4%, and 4.4% sloping irrigation furrows.

Study methods

The 1992 study was conducted at two sites, one on the University of Idaho (U of I) research farm 1.6 km (1 mile) northeast

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Table 1. Sediment outflows from USDA-ARS South Farm site 91-m furrows (1992)

	TREATMENT			
	Untreated	Whey	Straw	Straw + Whey
Irrigation No.	kg/ha			
1	7,260a	124b	70b	48b
2	25,829a	286b	1,000b	70b
3	10,623a	661b	1,622b	130b
4	6,421a	2,226b	2,468b	144c
5	4,000a	1,895b	2,160b	137c
6	3,027a	1,487b	862c	140d
7	1,921a	959b	786b	161c
8	1,613a	686b	502bc	156c
Total	60,694a	8,324b	9,470b	986b

Values in the same row with the same letter are not significantly different

of Kimberly, and the other on the USDA-ARS South Farm (ARS South Farm), 2.4 km (1.5 miles) southwest of Kimberly. The soil at both sites was Portneuf silt loam (coarse-silty, mixed, mesic, Durixerollic Calciorthid).

The U of I study area had previously been planted to sweet corn (*Zea Mays* L.), and the USDA-ARS South Farm to silage corn. Plots were plowed, roller-harrowed, chemically treated for weeds, furrowed, pre-plant irrigated, and planted to corn. All furrows in all treatments were 76 cm (30 inches) apart, center to center. The seedbed was clean-tilled and highly erodible because residue from the previous crop was completely turned under by moldboard plowing. These conditions are representative of local farming practices.

At each site, four treatments were replicated four times. The treatments were as follows: (1) untreated (control); (2) whey only; (3) straw only; and (4) straw + whey. Straw was applied by hand at both sites (treatments 3 and 4) at 1.8 kg/30 m (4 lb/100 ft), equivalent to 780 kg/ha (700 lbs/acre). Cottage cheese whey was then applied by gravity flow to treatment 2 and 4. The whey used for this study was the byproduct of adding an equivalent of 3 g of concentrated phosphoric acid (H_3PO_4) to one kg of milk resulting in 0. 3% acid. The whey, as applied to the field, contained 21 mmol Ca, 4 mmol Mg, 16 mmol Na and 42 mmol K kg^{-1} with an SAR of 3, pH of 3.3 to 3.8 and an EC of $7.7 dSm^{-1}$. The whey was obtained from a local cheese plant and hauled to the experiment site in a 2,800 l (750 gal) tank truck. It was applied at 190 l/min (50 gal/min) rate until 280 l (75 gal) had flowed into each treated furrow. This rate was sufficient to wet the furrow sides. There was very little within-furrow erosion during the application because of the whey's acid nature, viscosity and stickiness. Whey additions were ended when the flow had reached 75% of the furrow length, but the whey advance continued to move for a few minutes. The whey stream did not reach the furrow ends and thus did not flow out of the plot area. All treated furrows received whey, straw, or whey + straw at the beginning of the growing season, and were allowed to dry and settle at least three days before the first irrigation. Whey was applied June 11, 1992, and the first irrigation occurred June 16, 1992, at the ARS South Farm site. At the U of I site, whey was applied July 6, 1992, and the first irrigation occurred July 9, 1992.

Some fields in southern Idaho vary in slope from the upper to lower end. The U of I plots were located on such a field. The total furrow length was 60 m (200 ft). The upper 30 meters (100 ft) had a 2.4% slope while the lower 30 meters had a 4.4% slope. Two small trapezoidal flumes were placed in each 60 m test furrow, one at 30 m from the furrow top and the second flume at the lower end 60 m from the furrow top, for flow rate measurements.

Irrigation water at the U of I site was applied at 11 l/min (3 gal/min) to all treatments for seven irrigations. Water moved through the upper 30 meters, and passed through the first flume where the flow rate was measured, and runoff samples were collected for sediment concentration determination. Data collected at this point were used to calculate sediment loss by the Imhoff cone method (Sojka et al. 1992), and infiltration by subtracting outflow from inflow. For discussion purposes data collected here will be referred to as "upper section." The water leaving these first flumes continued through the lower 30 meters and passed through the second flume. Data collected at this point were used to calculate sediment loss and infiltration for the total 60 meters of the field, and will be referred to as "total length" data. The duration of each irrigation was 12 hours.

Plots at the ARS South Farm site were 91 m (300 ft) long on a 2.3% slope. Data for calculating sediment loss and infiltration were collected as the tail water passed through trapezoidal flumes located 91 m (300 ft) from the furrow inflow points. Irrigation water was applied at 15 l/min (4 gal/min) to all furrows in all treatments for eight irrigations.

During the first scheduled irrigation at the ARS South Farm a sudden storm developed with high velocity wind carrying freezing rain. As a result, the first irrigation was terminated after only 2.5 hours. All subsequent irrigations were 12 hours in duration.

Results and Discussion

Sediment loss. The untreated plots on the ARS South Farm lost the most sediment in every irrigation with the highest single sediment discharge occurring during irrigation 2 (Table 1), where sediment loss decreased from a high of 25,829 kg/ha during irrigation 2 to a low of 1,613 kg/ha during the final irrigation. Low losses in the first compared to the second irrigation showed the impact of the storm impacted irrigation. The greatest sediment loss from the whey treated plots occurred during irrigation 4, and then losses gradually decreased for subsequent irrigations. Organic material in whey is readily decomposable, so, as the organic material decomposed it appeared to have lost most of its effectiveness in reducing erosion by the fourth irrigation. Some rechanneling during irrigations 4 and 5 increased sediment loss, but the furrows had stabilized by irrigation 6. Sediment loss from straw + whey treated plots tended to increase slowly as the season progressed. Sediment outflows from this treatment were significantly less than for all other treatments during irrigations 4, 5, 6, and 7.

Sediment loss from whey + straw was significantly less than from untreated or whey treated plots for irrigation 8. The sediment outflow totals from all three treated plots were significantly less than from the untreated plots, but were not significantly different from each other, at the 5% probability level. Although the numerical magnitude for total sediment loss of treatments 2 and 3 were much higher than treatment 4, they were not significantly different from each other (Table 1). This was because of the high variability, e.g., standard error was 6711, 1314, 1105 and 53 for treatments 1, 2, 3, and 4, respectively. Season-long sediment reduction for whey + straw was over 98% less than for the untreated plots. Whey alone reduced erosion by 86% and straw alone by 84%.

Peak sediment outflows, from the upper section at the U of I site, occurred during irrigation 1 for untreated plots, irrigation 4 for whey plots, irrigation 2 for straw plots and irrigation 3 for straw + whey plots (Table 2). Sediment loss was significantly lower for straw and straw + whey treated plots compared to whey and untreated plots during irrigations 3, 4, 5, and 6, and for untreated plots for all 7 irrigations. Sediment loss for whey treated plots was significantly lower than from untreated plots for only irrigations 1 and 2.

However, the season total sediment loss from the upper section was significantly lower from all treated plots than from the control.

Sediment outflows from the total length at the U of I site peaked during irrigation 1 for untreated plots, irrigation 3 for whey, irrigation 2 for straw and irrigation 5 for straw + whey (Table 3). Sediment loss was significantly lower from straw and straw + whey treated plots than from untreated plots during all 7 irrigations. Sediment loss was significantly lower from straw treated plots than from whey and untreated plots during irrigations 3 through 7. Only during irrigation 1 was sediment loss from whey treated plots significantly lower than from untreated plots. The season total sediment loss from the total length was significantly lower for straw and straw + whey treated plots than from whey and untreated plots.

At the University of Idaho site some rechanneling increased sediment loss in the straw plots in the 4.4% slope portion during irrigations 2, 3, and 4. In the upper section, where greater erosion appeared in the untreated and whey treated plots, "clean" water entering the furrows stripped away chunks of the wetted furrow perimeter (Brown et al. 1988); erosion channels were wider and did not reach the lime-silica cemented subsoil. The "sediment enriched" water entering the 4.4% slope portion of the total length, formed a seal coat in the beginning (Brown et al. 1988).

However, the moving water eventually caused headcuts (waterfalls), destroyed the seal coat, permitted erosion to deepen the furrows to about 20 cm until the lime-silica cemented subsoil was reached, and then vertical erosion subsided.

Straw + whey was the most effective treatment for reducing sediment outflows from both the upper section and the total length, with a reduction in sediment loss of 97 and 96%, respectively, as compared to the control plots. Straw alone reduced sediment outflows by 89 and 76% for upper section and total length, respectively. Reduction of sediment outflows for whey alone was 49% for the upper section but that treatment was not significantly better than the control for the total length. Both the straw and straw + whey treatments reduced the flow velocity of the irrigation stream and reduced the abrasion of the wetted furrow perimeter compared to the non-straw treatments. However, whey alone also reduced sediment outflows for both slopes in relation to the control for some irrigations.

Water infiltration and lateral movement. Infiltration for whey at the ARS South Farm site was always above untreated furrows (Table 4) except for irrigation 1 which had a 2 1/2 hour duration because a severe storm developed. Water was applied at the same flow rate to all treatments. During irrigation 1 water infiltrated 1.4 l/m (.4 gal/min) slower into the whey furrows compared to the untreated furrows for the following reasons. Initially, soil aggregates in whey furrows were very stable and impermeable for about the first 1 1/2 hours which allowed water to move more quickly down the furrow infiltrating at 3.4 l/min (0.9 gal/min). As the irrigation progressed, soil cracks developed in the whey furrows that increased the permeability resulting in increased infiltration. On the other hand, initially soil in untreated furrows was very dry, cloddy and porous which increased water intake until the pores became filled with sediment fines to form a soil seal coat (Brown et al. 1988). Water infiltrated 4.8 l/min (1.3 gal/min) into the untreated furrows. By the end of irrigation 1 infiltration in the whey furrows was beginning to equal

Table 2. Sediment outflows from the upper 30-m furrows (upper section) at the university site (1992)

	TREATMENT			
	Untreated	Whey	Straw	Straw + Whey
Irrigation No.	kg/ha			
1	28,588a	5,250b	2,039b	340b
2	17,066a	7,364b	2,339b	274ba
3	12,502a	8,552a	1,170b	381b
4	8,011a	9,371a	1,131b	340b
5	5,063a	4,457a	647b	320b
6	3,461a	2,843a	567b	358b
7	1,784a	1,359ab	520bc	291c
Total	65,475a	39,196b	8,413c	2,304c

Values in the same row with the same letter are not significantly different

Table 3. Sediment outflows from the 60-m furrows (total length) at the university site (1992)

	TREATMENT			
	Untreated	Whey	Straw	Straw + Whey
Irrigation No.	kg/ha			
1	12,935a	3,208b	1,833b	103b
2	9,409a	6,550ab	3,063bc	184c
3	7,194a	8,823a	1,591b	178b
4	4,962a	6,154a	2,017b	505b
5	4,019a	3,942a	541b	207b
6	2,546a	2,570a	589b	284b
7	1,553a	2,001a	395b	152b
Total	42,618a	33,248a	10,029b	1,613b

Values in the same row with the same letter are not significantly different

Table 5. Infiltration in the 30-m furrows (upper section) at the university site (1992)

	TREATMENT			
	Untreated	Whey	Straw	Straw + Whey
Irrigation No.	kg/ha			
1	544c	548c	1,286a	977b
2	804a	825a	1,153a	959a
3	776b	892ab	1,237a	1,009ab
4	912a	1,047a	954a	1,098a
5	818b	1,093a	890ab	1,022a
6	752a	962a	838a	900a
7	942a	1,211a	1,067a	1,231a
Total	5,548b	6,578a	7,425a	7,196a

Values in the same row with the same letter are not significantly different

Table 4. Infiltration from USDA-ARS South Farm site 91-m furrows (1992)

	TREATMENT			
Irrigation No.	Untreated	Whey	Straw	Straw + Whey
	kg/ha			
1	130b	100b	223a	139b
2	676b	762b	757b	1,147a
3	603b	653ab	525b	817a
4	459b	710a	499b	691a
5	504b	674a	470b	738a
6	508b	632b	612b	820a
7	582b	623ab	481c	658a
8	601a	651a	691a	710a
Total	4,063b	4,805b	4,258b	5,720a

Values in the same row with the same letter are not significantly different

Table 6. Infiltration in the 610-m furrows (total length) at the university site (1992)

	TREATMENT			
Irrigation No.	Untreated	Whey	Straw	Straw + Whey
	kg/ha			
1	429a	629a	840a	602a
2	466a	523a	672a	599a
3	405c	506bc	631ab	709a
4	462b	468b	595ab	722a
5	425b	523ab	672a	727a
6	390b	524ab	595a	675a
7	571c	648bc	784ab	851a
Total	3,148c	3,821b	4,789a	4,885a

Values in the same row with the same letter are not significantly different

and surpass the untreated furrows. Infiltration in the whey furrows would have surpassed the untreated furrows had irrigation 1 lasted 12 hours.

A significantly greater amount of water infiltrated into the straw treated furrows (Table 4) compared to the other three treatments; the loose straw created mini-dams that slowed the water and increased the wetting perimeter. Straw + whey plots had a significantly greater amount of water infiltrate during irrigations 2 through 7, than in untreated or straw treated plots. There was no significant infiltration difference among the four treatments during irrigation 8. For the irrigation season, infiltration into the straw + whey treated furrows was significantly higher than for other treatments which did not differ significantly from each other.

Infiltration varied among treatments for specific irrigations on the upper section of the U of I site (Table 5) but no consistent pattern was evident. For example, both straw and straw + whey caused significantly more infiltration than the control or whey in irrigation 1, but those differences did not persist in irrigation 2. During irrigation 3, straw caused significantly more infiltration than occurred on the control, but this difference did not persist with subsequent irrigations. All treatments caused significantly more seasonal infiltration than the control.

Infiltration during the irrigation season for the total length at the U of I site was significantly higher for all treated plots compared to untreated plots (Table 6). As the season progressed, there was a tendency towards significantly greater infiltration for all treatments than for the control. No significant differences were observed the first two irrigations, but by irrigation 3 both straw and straw + whey provided conditions for significantly more infiltration than the control, and these differences continued with all subsequent irrigations. Whey alone did not increase infiltration significantly (P=0.05) over the control for any specific irrigation, but the total infiltration for the season was greater for the whey than for the control. Straw and straw + whey significantly enhanced total seasonal infiltration over both the control and whey treatments.

Erosion reduction and increased water lateral movement in all treated furrows compared to the untreated furrows was evident. Soil in the furrow bottoms became stabilized when whey was applied. For example, a jagged soil ridge having about a 3.8 cm (1.5 inch) drop created a water fall when whey was applied. The soil then dried before the first irrigation. Water flowed over that ridge during seven 12-hour irrigations without the ridge being destroyed by water action. Whey alone prevented deep furrow cutting and maintained relatively wide furrow wetted surface that increased lateral water movement compared to the untreated furrows. Initially, water applied at the same flow rate to all treatments moved more quickly through the whey plots because of reduced resistance. Cracks did, however, develop in the whey treated furrows which allowed water to penetrate both laterally and downward. There was some rechanneling of the furrow stream that undercut the side-walls of the straw treated furrows. The moving sediment partially covered straw in the furrows. The flowing water removed a very small amount of the shortest straw from the furrows. In the straw + whey treatment, straw was held in place by the sticky whey rather than by the suspended sediment as in the straw treated furrows.

Conclusion

This research shows that a one-time application of two low-cost agricultural byproducts, cottage cheese whey and straw, to irrigation furrows having different slopes can significantly reduce soil loss and increase infiltration. These treatments can conserve soil, water and plant nutrients. Compared to untreated furrows at the ARS South Farm site, straw alone significantly reduced season-long sediment outputs by 84%. The straw became partially covered and held in place by sediment. Straw created mini-dams that slowed the water which increased the wetted perimeter causing higher infiltration. Whey alone likely reacted with the soil at application time to increase the stability. Several soil reactions take place with the acid whey to produce cementing agents that increase the soil stability. As a result, whey alone was effective in significantly reducing sediment loss by 86%. Persistent cracks in the soil developed in the whey treated furrows that increased infiltration. Whey + straw had the greatest effect on reducing erosion and increasing infiltration compared to the other three treatments. Straw + whey reduced erosion by 98%.

The total sediment loss from the U of I upper section was significantly lower for all treated plots than from the control. Total sediment loss from the total length was significantly lower for straw and straw + whey treated plots than from whey and untreated plots.

For the irrigation season, infiltration at the ARS South Farm site was significantly higher for straw + whey than for other treatments which were not significantly different from each other. At both U of I sites all treatments caused significantly more seasonal infiltration than the control.

Studies are continuing to determine the most effective combination of straw and whey to reduce sediment movement and increase infiltration. Both byproducts will be applied using standard, commonly available farm equipment.

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