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Whey utilization in furrow irrigation: Effects on aggregate stability and erosion

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ABSTRACT

Improving soil structure often reduces furrow erosion and maintains adequate infiltration. Cottage cheese whey, the liquid byproduct from cottage cheese manufacture, was utilized to stabilize soil aggregates and reduce sediment losses from furrow irrigation. We applied either 2.4 or 1.9 L of whey per meter of furrow (3.15 or 2.49 L m^{-2}, respectively) by gravity flow without incorporation to two fields of Portneuf silt loam (Durinodic Xeric Haplocalcid) near Kimberly, ID. Furrows were irrigated with water beginning four days later. We measured sediment losses with furrow flumes during each irrigation and measured aggregate stability by wet sieving about 10 days after the last irrigation. Overall, whey significantly increased aggregate stability 25% at the 0–15 mm depth and 14% at 15–30 mm, compared to controls. On average, whey reduced sediment losses by 75% from furrows sloped at 2.4%. Whey increased the aggregate stability of structurally degraded calcareous soil in irrigation furrows.

1. Introduction

Cheese whey is the liquid byproduct of cheese manufacture. In the US, nearly 44×10^6 Mg of whey are produced annually in the manufacture of hard and cottage cheeses (National Agricultural Statistics Service, 2007). While whey varies in character depending upon cheese production process, it is generally a mild acid with high soluble salt, chemical oxygen demand (COD), and fertilizer nutrient content, compared to most other waste waters (Robbins and Lehrsch, 1998). Whey is often about 8% solids and commonly contains 40–50 g kg^{-1} of readily decomposable organic compounds, primarily proteins and lactose (Kelling and Peterson, 1981). Some wheys contain more than 1000 mg Na^{+} kg^{-1}, limiting their usefulness in agriculture (Robbins and Lehrsch, 1998).

Incorporated low-Na^{+} whey improves impaired chemical and physical properties of sodic soils (Robbins and Lehrsch, 1992; Jones et al., 1993b; Lehrsch et al., 1994). Soluble salts in the whey reduce the diffuse double-layer thicknesses of clays, promoting flocculation. Adding and incorporating lactose and whey proteins in soil stimulate aerobic microbes that produce polysaccharides and other organic extracellular compounds and promote fungal growth (Sonnleitner et al., 2003), both of which aid the formation and subsequent stabilization of soil aggregates (Amézketa, 1999; Lynch and Bragg, 1985; Roldán et al., 1996). Soil structural improvements on eroded and/or degraded lands are often necessary during rehabilitation (Logan, 1992). If whey improves the structure of eroded or non-sodic soil, its use as a soil amendment would transform an often discarded byproduct into a valuable resource, providing cheese producers in certain localities another income stream or, in other areas, reduced disposal costs. Since whey is mostly water, its use as a soil amendment is economically feasible only near the whey source if transportation costs are borne solely by the landowner (Zall, 1980; Robbins and Lehrsch, 1998).

Erosion from furrow-irrigated cropland decreases yield potential (Carter, 1993) and degrades surface water quality (Carter, 1990; Lentz et al., 1996). Techniques to control furrow irrigation-induced erosion include vegetated filter strips, mini-basins, residue placement in furrows, and polyacrylamide (PAM) treatment of furrow irrigation water (Brown et al., 1998; Brown and Kemper, 1987; Carter, 1990; Lentz and Sojka, 1994). PAM treatments are particularly effective and widely adopted (Lentz and Sojka, 1994; Sojka et al., 2007).

An alternative or complimentary approach to reducing furrow erosion may be to stabilize aggregates at and below furrow wetted perimeters by applying whey to soil. Kelling and Peterson (1981), studying acid soils in Wisconsin, observed that whey-induced increases in aggregate stability were associated with reduced erosion rates. Bjorneberg et al. (1999), in contrast, in a study of furrow erosion from manure- and whey-treated topsoil and subsoil, noted that soil loss from whey-treated topsoil was among the highest they measured. In their study, however, whey had been applied nearly four years earlier. Since whey is oxidized by soil microbes within a month or two after application (Kelling and Peterson, 1981; Robbins and Lehrsch, 1998), the erosion responses they

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detected were not likely a consequence of the whey applied 46 months earlier.

Brown et al. (1998) reported that whey and small grain straw placed in irrigation furrows effectively decreased irrigation-induced erosion and increased seasonal infiltration. They did not, however, identify the physical processes operating or the mechanisms responsible for reduced erosion from whey-treated furrows. In their study, whey was applied without incorporation to non-sodic soil surfaces prior to irrigation but whey effects on soil structure were not measured. After irrigating, they observed that a surface seal, indicative of soil structural breakdown, had formed along the wetted perimeters of furrows that had not received whey. However, where whey was applied, surface aggregates appeared to be more stable, especially during the first few hours of the first irrigation after whey application. This observation is consistent with previous work showing that soil erodibility and erosion often decrease as aggregate stability increases (Luk, 1979; Kemper et al., 1985; Barthès et al., 2000). In some instances, erodibility and erosion increase with aggregate stability for reasons not yet known (Amézketa, 1999).

Whey is known to increase aggregate stability where it is incorporated into the surface of structurally weak, sodium-affected soils (Robbins and Lehrsch, 1992; Lehrsch et al., 1994). We do not know, however, whey effects on the structure of calcareous but non-sodic soils. Nor do we know whether surface-applied whey must be incorporated for its effects on the structure of such soils to be manifest. Whey effects on calcareous soils need to be further elucidated (Amézketa, 1999; Douglas et al., 2003). We hypothesized that whey applied to furrows of non-sodium-affected soils before they were irrigated would increase the stability of aggregates at and below furrow-wetted perimeters. Stable aggregates along the wetted perimeter would resist slaking and reduce seal formation, thus maintaining acceptable infiltration and aeration (Brown et al., 1988). Greater infiltration would also reduce down-furrow flow rates and hydraulic shear imposed on the wetted perimeter. Both detachment and transport would be minimized, thereby reducing sediment loss rates (Trout and Neibling, 1993; Lehrsch et al., 2005). In this study, we determined whey effects on aggregate stability in and sediment losses from irrigation furrows on two calcareous field sites in 1991.

2. Methods

2.1. Soil and whey properties

The study was conducted on a Portneuf silt loam (coarse silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid) near Kimberly, ID, USA. The Portneuf soil formed in loess and its Ap horizon had a saturated paste pH of 7.7, about 9.3 g organic C kg^{-1}, 220 g clay kg^{-1}, and 560 g silt kg^{-1}. The Portneuf's water content is 0.24 kg kg^{-1} at field capacity and 0.10 kg kg^{-1} at the permanent wilting point (McDole et al., 1974). Portneuf soil structure is relatively unstable (Lehrsch et al., 1991) and the soil is susceptible to furrow erosion (Lehrsch and Brown, 1995). Our cottage cheese whey was the byproduct of adding the equivalent of 3 g H_3PO_4 kg^{-1} of milk to coagulate milk proteins. Each kilogram of whey contained about 1100 mg P, 2000 mg K^+, 960 mg Ca^{2+}, 120 mg Mg^{2+}, and 440 mg Na^+. Though not measured, the whey's total nitrogen content was likely about 1500 mg N kg^{-1} (Robbins and Lehrsch, 1998). The whey had a pH of 3.3, an electrical conductivity (EC) of 5.4 dS m^{-1}, a sodium adsorption ratio (SAR) of 3.5, and a density of 1.01 Mg m^{-3} (Lehrsch et al., 1994). Though representative in most respects, this whey had about 25% less EC, 25% less Na^+, and 65% more K^+ than the cottage and creamed cheese wheys reported by Robbins and Lehrsch (1998).

Table 1
Sequence of field operations

Date	Operation	
	Site A	Site B
24 October 1990		Moldboard plowed[a]
5 April 1991[b]	Moldboard plowed	
8 April 1991	Roller-harrowed[a] twice	Roller-harrowed
6 May 1991	Furrowed, pre-plant irrigated	
13 May 1991	Applied herbicide and fertilizer, roller-harrowed twice, planted maize[c] (*Zea mays* L.), furrowed	Applied herbicide and fertilizer, roller-harrowed twice, planted maize, furrowed
16 May 1991[b]		Irrigated
11 June 1991[b]	Cultivated[a]	Cultivated
14 June 1991	Applied whey	Applied whey
18 June 1991	Irrigated	
25 June 1991		Irrigated
2 July 1991	Irrigated	
8 July 1991		Collected soil samples
9 July 1991	Collected soil samples	

[a] Plow was operated to a depth of 0.18 m; roller-harrow to 60 mm; cultivator to 50 mm.
[b] Date is approximate.
[c] Maize row spacing was 0.76 m.

2.2. Statistical design and analyses

We used a split-plot design with treatments (Whey or Control) as main plots and sampling depths (0–15 or 15–30 mm) as subplots when analyzing aggregate stability. At each site, the treatments were randomized in each complete block but the whey treatment was duplicated in each block. Consequently, the whey treatment was replicated ten times and the control five times, with each replicate being one furrow. The experimental design was a randomized complete block when analyzing erosion rates, assumed to be equal to sediment loss rates and referred to as such hereafter. After ensuring that each response variable's treatments had homogeneous variances, analyses of variance were performed using SAS (SAS Institute Inc., 1999).[1]

2.3. Site preparation, whey application, and irrigation

The major field operations on each site were similar, though not always performed on the same day (Table 1). Furrows were 0.76 m apart. Before whey was applied, soil in every furrow was cultivated with a single, 0.25 m-wide sweep, operated at a depth of 50 mm in soil with water contents commonly ranging from 0.05 to 0.08 kg kg^{-1}, drier than the Portneuf's permanent wilting point. Behind each cultivator sweep, we positioned a weighted furrowing tool that re-formed triangular-shaped furrows about 0.18 m wide at the top and 0.1 m deep. After cultivating all plots, we waited three days for the aggregates to strengthen as the soil dried (Kemper and Rosenau, 1984), then applied whey to the treated plots as described below. Thereafter, with no subsequent tillage, all plots were irrigated with water twice (Site A) or once (Site B) as described below, and subsequently sampled. The control plots were cultivated and irrigated in the same manner as the whey-treated plots but received no whey prior to irrigation.

Site A was at 42°32′55″ N latitude, 114°20′13″ W longitude, and had an elevation of 1184 m. Its furrow slopes faced east and averaged 2.4%. A total of 260 L of whey was applied, at an inflow rate of 150 L min^{-1}, to the head of each 30.4 m-long treated furrow on 14 June. Burlap protected the soil surface where the whey entered

[1] Manufacturer or trade names are included for the readers' benefit. The USDA-ARS neither endorses nor recommends such products.