CHEESE WHEY AS AN AMENDMENT TO DISTURBED LANDS: EFFECTS ON SOIL HYDRAULIC PROPERTIES[1]

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Abstract: Whey, the liquid byproduct of cheese production, can improve minesoils by increasing the aggregate stability of soils high in sodium or susceptible to erosion. Whey effects on soil hydraulic properties, however, are not known. In this experiment, we determined whey effects on infiltration rates (at water potentials of −30 mm or less) and unsaturated hydraulic conductivities of surface soil horizons after a winter wheat (*Triticum aestivum* L.) growing season. The experimental design was a randomized complete block with three replications of four liquid whey application treatments, totaling either 0, 202, 404, or 808 Mg/ha (control, low, medium, and high, respectively). In Fall 1992 near Kimberly, ID, a field of Portneuf silt loam (*Durixerollic Calciorthid*) was leveled, subsoiled, then roller-harrowed twice. After planting Malcolm wheat on September 15, we furrowed all plots and then constructed a berm around each. At 3-week intervals beginning on May 19, 1993, either zero, one, two, or four flood applications of 202 Mg/ha of whey were made to each plot, without subsequent tillage. After August wheat harvest, a tension infiltrometer was used to measure vadose zone, unsaturated flow characteristics in the bottom of undisturbed furrows, where most whey had infiltrated. Infiltration rates at potentials of −60 and −150 mm decreased linearly as whey applications increased from 202 to 808 Mg/ha. At a potential of −60 mm, hydraulic conductivity increased but then decreased with whey additions. In short, soil hydraulic properties were little affected by surface whey additions of 404 Mg/ha or less.

Additional Key Words: infiltration, hydraulic conductivity, tension infiltrometer, food processing wastes.

Introduction

The soils of lands disturbed by human activities often exhibit characteristics that make land reclamation difficult. Plant establishment and/or growth is often inhibited by excess acidity or alkalinity, or the presence of toxic metals or excess salts (Logan 1992). Less frequently, land may be contaminated with relatively high concentrations of sodium, radionuclides, toxic organics, or even excess plant nutrients (Hossner and Hons 1992, Logan 1992, Power et al. 1974). Physical properties, as well, may be adversely affected. Texture, bulk density, and structure are frequent impediments to seed germination or plant growth (Hossner and Hons 1992). Coarse-textured materials commonly have limited water-holding capacities, are low in organic matter (and hence in cation exchange capacity), and are prone to surface crust formation (Hossner and Hons 1992, Zabowski et al. 1993). Fine-textured materials, while they can hold more water, can have lower infiltration rates, hydraulic conductivities, or anaerobic root zones (Sopper 1992, Zabowski et al. 1993).

To correct one or more of these plant-growth limiting characteristics, inorganic and/or organic amendments are often added to the soils of disturbed landscapes. Inorganic amendments include fertilizer, lime, elemental sulfur, and gypsum (Logan 1992, Robbins and Gavlak 1989, Zabowski et al. 1993). Organic amendments, because they add nitrogen and organic material as well as improving soil physical properties such as permeability and porosity, are widely used (Logan 1992, Sopper 1992). Sewage sludge is also frequently applied (Haering and Daniels 1992, Sopper 1992). Other organic amendments include papermill sludge, cement kiln dust-stabilized sludge, municipal solid waste, compost, manure, plant residues, and wastewater

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(Logan 1992, Robbins and Gavlak 1989, Zabowski et al. 1993). Cheese whey, the liquid byproduct of cheese production, has also been used as an organic amendment to help reclaim soils high in sodium (Jones et al. 1993, Lehrsch et al. 1994, Robbins and Lehrsch 1992). A sodic soil, by definition, has a saturation paste extract electrical conductivity (EC_e) ≤ 4 dS/m and a sodium adsorption ratio (SAR) >13 (Richards 1954).

Whey is readily available at cheese production facilities. In the United States in 1991, the production of 366,000 Mg of creamed and low-fat cottage cheese (U.S. Crop Reporting Board 1992) generated nearly 3 million Mg of acid whey (Jones et al. 1993). Though often fed to poultry or livestock, whey is frequently considered a waste product and disposed of in sewage treatment facilities or by land application (Watson et al. 1977), nearly always at a cost to the cheese producer. When whey is available at little or no cost, it is an attractive organic amendment.

Whey's potential as an amendment for land reclamation, particularly in the western United States where soils can be affected by relatively high levels of sodium and/or lime, is great. The low pH of the whey decreases soil solution pH and thus increases Ca solubility. Microorganisms, as they decompose the lactose and proteins in the whey (Summers and Okos 1982), produce CO_2 and organic acids that also increase Ca solubility (Robbins 1985). All of these processes will speed the leaching of exchangeable Na from a sodic soil profile when sufficient water is passed through the soil. Lehrsch et al. (1993), in a study of the aggregate stability of non-sodic soils, noted that the addition of soluble salts (such as are present in cheese whey) to the soil solution should reduce the diffuse double-layer thicknesses of clay domains, resulting in clay flocculation. This improved aggregation changes the pore size distribution, usually increasing the flux density of both water and air through the soil profile (Hillel 1982). Adding and incorporating whey lactose stimulate aerobic microbes that produce polysaccharides that will stabilize aggregates (Allison 1968). In a greenhouse study, Kelling and Peterson (1981) found that an application of 25 mm of whey improved aggregation as much as did application of 22.4 Mg/ha of corn (*Zea mays* L.) residue. Lehrsch et al. (1994) found aggregate stability to increase from 25% to 80% when 808 Mg/ha of acid whey were surface-applied, then incorporated into sodium-affected soils. As aggregate stability increases, erosion decreases (Luk 1979). Watson et al. (1977) measured up to a fourfold increase in infiltration rates into a fallow, non-sodic soil about 3 months after a surface application of sweet whey. They attributed the marked infiltration increases to improved soil structure.

Cheese whey does, however, have disadvantages that may outweigh the advantages noted above. Acid whey cannot be economically dehydrated; thus, its large volume and mass make handling troublesome. If it is surface applied without incorporation, odor control may be necessary. Transportation distances, as with many potential amendments, must be relatively short for whey to be economically attractive.

Problems may also occur if too much whey is applied. High whey application rates could increase root zone salinity (Jones et al. 1993, Robbins and Lehrsch 1992, Sharratt et al. 1962). Excessive whey applications could also decrease infiltration rates in the short term owing to organic overloading (McAuliffe et al. 1982, Watson et al. 1977). Organic overloading in particular can make management and/or reclamation difficult. Two sweet whey applications, each 200 mm or more, by Watson et al. (1977) decreased ponded infiltration rates by 13% to 67%. McAuliffe et al. (1982) found saturated hydraulic conductivities to decrease by approximately 50% within 2 days after they applied only 35 mm of a dilute sweet whey. The hydraulic conductivities did increase, however, 1 to 3 weeks after the second whey application. Additional research on the use of acid whey for reclaiming both saline-sodic and sodic soils has been recommended (Robbins and Lehrsch 1992).

Despite these disadvantages, whey may still have value as an amendment for land reclamation, particularly for sites with soils high in sodium or susceptible to erosion. While the effects of whey on soil physical and chemical properties have been studied (Jones et al. 1993, Lehrsch et al. 1994, Robbins and Lehrsch 1992), its effects on soil hydraulic properties such as infiltration rates (at water potentials of −30 mm or less) or unsaturated hydraulic conductivities have received comparatively little attention. Thus, the objective of our study was to determine the effects of surface-applied whey on the hydraulic properties of surface soil horizons after a winter wheat growing season.

Materials and Methods

This experiment was conducted 2.2 km northeast of Kimberly, ID, on a Portneuf silt loam, previously cropped to barley (*Hordeum vulgare* L.). The Portneuf has 22% sand, 12% clay, 0.72% organic C, a pH of 7.6, and cation exchange capacity of 126 $mmol_c$/kg. In the fall of 1992, the site was leveled with a grader, subsoiled to a depth of 28 to 30 cm with shanks 30 cm apart, then roller-harrowed twice. This tillage was assumed to simulate the disturbance caused by soil replacement, deep ripping, and seedbed preparation during mined-land reclamation. On September 15, with no fertilizer, Malcolm wheat at a row spacing of 18 cm was planted; then furrows were formed every 76 cm in the surfaces of all plots. Two days after planting, owing to low soil water contents, the site was furrow-irrigated for 24 h. On May 3, 1993, we constructed berms of soil around each 10.7- by 15.2-m plot. The plots were sprayed on May 13 with 2,4-D for broadleaf weed control. To satisfy the wheat's transpiration demand, we used a solid-set sprinkler system to apply 65±16 mm (mean ± SD) of water in 24 h on May 25 and 76±14 mm in 28 h on June 30 and July 1. This water commonly has a pH of 8.2, an EC of 0.5 dS/m, and an SAR of 0.65 (Lehrsch et al. 1994).

The whey used in our study was trucked from a cheese plant 63 km east of our field site. The whey, a mixture of 75% sweet (from the production of hard or cheddar-type cheeses) and 25% acid (from the production of soft or cottage cheeses), contained 0.50±0.09 g P, 16.7±2.5 mmol Ca, 3.7±0.8 mmol Mg, 31.1±10.0 mmol Na, and 17.8±2.6 mmol K per kilogram. The pH was 3.5±0.7, the EC was 7.8±1.3 dS/m, the SAR was 6.9±1.8, the chemical oxygen demand was 57,200±5,500 mg O_2/L, and the density was 1.01 g/cm^3. At each application, 202 Mg/ha of whey (equivalent to a 20-mm depth) flowed by gravity through layflat irrigation tubing from a tank truck to a plot where it flooded over the plot surface. The control plots did not receive whey. Each plot of the low treatment received a single whey application on June 8. Each plot of the medium treatment received a whey application on May 19 and June 29. Each plot of the high treatment received an application on May 19, June 8, June 29, and July 20. Wheat samples collected on July 30 were analyzed for total dry matter and other samples collected on August 2 for grain yield.

In August and September 1993, tension infiltrometers (Ankeny 1992) were used to measure unconfined (three-dimensional) infiltration rates at three locations in each plot, using a slight modification of the procedure outlined by Ankeny (1992). In the bottom of irrigation furrows, where most of the whey had infiltrated, infiltration was measured without disturbing the soil surface and from low to high water potentials (−150 to −60 to −30 mm, or from −1.47 to −0.59 to −0.29 kPa). At a water supply potential of −30 mm, flow occurs through pores with diameters of 1 mm or less, at a potential of −60 mm through diameters of 0.5 mm or less, and at a potential of −150 mm through diameters of 0.2 mm or less (Marshall and Holmes 1979). Software described by Ankeny et al. (1993) was used to determine steady-state infiltration rates, and from them, to calculate unsaturated hydraulic conductivities. From these properties, we calculated both macroscopic and microscopic capillary lengths (White and Sully 1987, White et al. 1992). The use of tension infiltrometers and their applications in the study of soil structural changes induced by tillage, precipitation, and biological activity have been reviewed by White et al. (1992).

The experimental design was a randomized complete block, with four whey application treatments, three replications, and three subsamples per replication. Whey treatment means were separated using a least-squares estimation procedure with a significance probability of 5%. The relationship between treatment means and standard deviations was used to ensure that the frequency distribution of each response variable was near normal. When necessary, a common logarithmic transformation was employed to normalize a variable's distribution.

Results and Discussion

At a water potential of –30 mm, whey additions affected neither the infiltration rate nor the hydraulic conductivity (data not shown). While trends were evident in the response of both infiltration rate and hydraulic conductivity (similar to responses at lower potentials discussed in more detail below), the differences were not significant at the 5% level. Spatial variability in large pores (equivalent diameters on the order of 1 mm, Marshall and Holmes 1979) at the soil surface likely made significance difficult to detect.

Macroscopic capillary length, essentially a flow-weighted mean soil water potential (somewhat analogous to capillary rise above a water table), and microscopic capillary length, as a representative flow-weighted mean pore radius, responded as expected. At water potentials of –60 and –150 mm, macroscopic capillary lengths decreased, in general, and microscopic capillary lengths increased, in general, with whey additions. The responses, usually significant at 10%, were not significant at 5% and thus have not been presented.

The infiltration rates, at a water potential of –60 mm, into irrigation furrows decreased linearly with whey additions (fig. 1). As the whey application increased from 404 to 808 Mg/ha, the infiltration rate decreased significantly (P=0.01), from 6.26 to 2.74 μm/s. At this highest whey application rate, the soil may have been organically overloaded so that suspended solids and/or microbiological growth clogged pores at or near the soil surface, reducing infiltration rates and hydraulic conductivities (McAuliffe et al. 1982). Alternatively, this 56% decrease could have been caused by the formation of a depositional seal, possibly due to a deterioration of soil structure, along the furrow's wetted perimeter as a result of the high whey application. The stability of macropores, as well as aggregates, influences soil hydraulic properties (Murphy et al. 1993). Lehrsch et al. (1994) found the percentage of stable aggregates in largely undisturbed soil to drop from 64% to 46% as cottage cheese whey applications to a silt loam soil in southern Idaho increased from 505 to 1,010 Mg/ha.

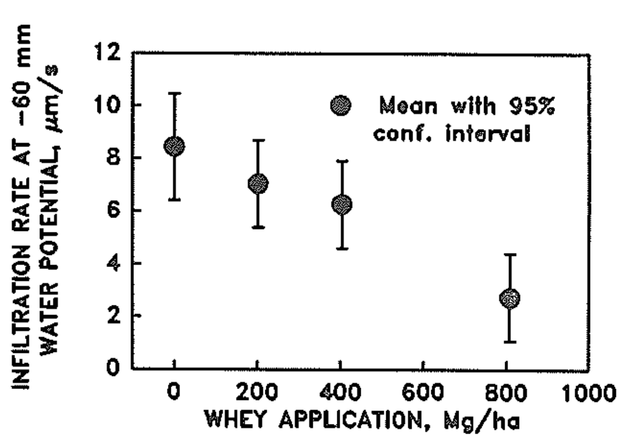

Figure 1. Infiltration rate at a water potential of –60 mm as a function of whey appplication.

In a similar manner, even at a much lower water potential of –150 mm, infiltration into the bottoms of treated furrows still decreased monotonically as more and more whey was applied (fig. 2). After the medium and high whey applications, the infiltration rates, 3.48 and 1.70 μm/s, respectively, were significantly <u>less</u> ($P \leq 0.015$) than the control, 6.81 μm/s. In an earlier study on a saline-sodic soil, Jones et al. (1993) found, however, that acid whey applications of up to 1,010 Mg/ha did not adversely affect ponded infiltration (water potentials ≥0).

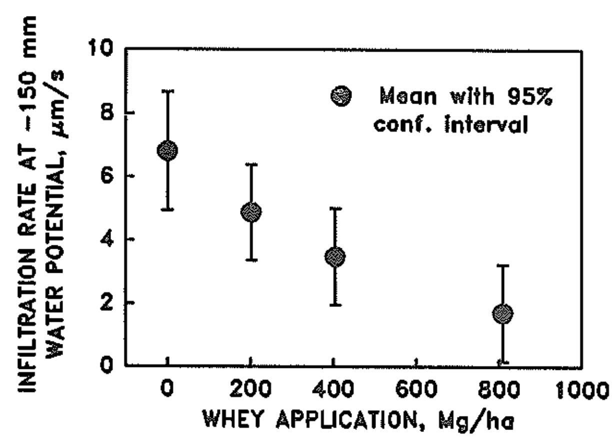

Figure 2. Infiltration rate at a water potential of –150 mm as a function of whey application.

Infiltration rates at potentials of –60 mm or less decreased with whey additions (figs. 1-2). At potentials of –60 mm or less, water flowed through pores 0.5 mm or less in diameter. This indicates that the effect of whey additions on the pore size distribution in the soil along the furrow's wetted perimeter is consistent on pores ≤0.5 mm in diameter. That is, if the whey primarily affected pores with diameters greater than 0.2 mm, the effect of whey additions upon the infiltration rate at a water potential of −150 mm should be negligible. Such was not the case (fig. 2).

The deleterious effect of cheese whey upon furrow infiltration rates at water potentials less than −60 mm is significant from a management standpoint. If the intention is to maintain furrow infiltration, even under tension, at levels comparable to those under undisturbed conditions, cheese whey addition rates may need to be limited to rates of 404 Mg/ha or less over the summer growing season to silt loam soils in southern Idaho.

The only other hydraulic property that we studied upon which whey applications exerted a statistically significant effect was hydraulic conductivity at a water potential of −60 mm (fig. 3). The effect of whey upon unsaturated hydraulic conductivity, however, was quite different from its effect upon infiltration (figs. 1-2). As whey additions increased from 202 to 404 Mg/ha, flow through pores with equivalent diameters of 0.5 mm or less increased (fig. 3). The decrease in infiltration rate (fig. 1) and the accompanying increase in hydraulic conductivity (fig. 3) are apparently due to a depositional crust effect where pores 0.5 mm or less in the crust are obstructed while similar pores below the crust are rendered more stable. At whey application rates up to 404 Mg/ha, the microorganisms are utilizing the whey for food and, consequently, are producing polysaccharides that may be stabilizing aggregates adjacent to the flow paths below the crust. As more whey was applied, however, unsaturated hydraulic conductivity exhibited a marked (and significant, P=0.009) decrease from that at the 404 Mg/ha rate, though not from that of the control (fig. 3). At higher whey rates, the system may be organically overloaded and, below the depositional crust, suspended solids or the microorganisms themselves may be blocking the conducting pores, thus reducing the hydraulic conductivities. With excessive whey applications, hydraulic conductivities have decreased under certain circumstances (McAuliffe et al. 1982).

Based in part upon the findings of this study, if application rates are not too high, cheese whey may be used as an amendment to disturbed lands without affecting soil hydraulic properties excessively. Cheese whey, if added at rates less than or equal to 404 Mg/ha, may not decrease furrow infiltration rates (at potentials ≥−60 mm) markedly and may increase the hydraulic conductivity at a water potential of −60 mm.

Additional research is needed to better characterize the physical and hydraulic properties of soils to which whey, either acid or sweet or both, has been applied. Physical property changes, possibly revealed by changes in macroscopic or microscopic capillary lengths (White et al. 1992), occurring at and below the soil surface are not well known. Whey movement through preferential flow channels deeper into soil profiles is of interest, particularly since groundwater quality could be adversely affected by such flow (Kelling and Peterson 1981, Peterson et al. 1979). Further research should also examine the effects of whey incorporation by tillage on the physical and hydraulic properties of the surface soil. A likely increase in aggregate stability after tillage (Lehrsch et al. 1994) may offset the infiltration reductions with whey additions found in this study (figs. 1-2).

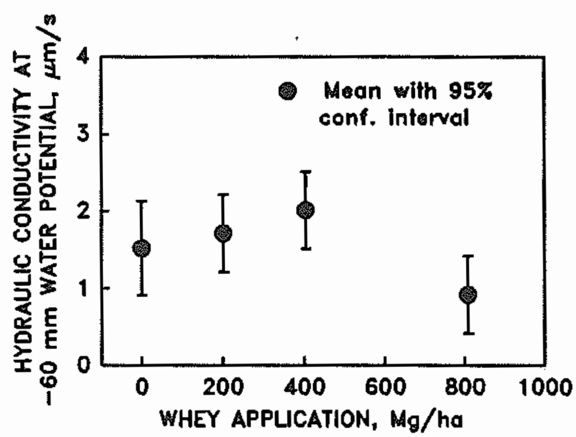

Figure 3. Hydraulic conductivity at a water potential of −60 mm as a function of whey application.

Conclusions

Cheese whey primarily affected the infiltration rate, at water potentials of −60 mm or less, through the bottoms of irrigation furrows. Infiltration rates decreased, in a linear or near linear manner, as whey applications increased from 202 to 808 Mg/ha. At water potentials of −60 and −150 mm, the infiltration rate into the 808-Mg/ha plots was significantly less than that into the control. Whey additions also affected the hydraulic conductivity at a potential of −60 mm, though in a different manner. Whey additions up to and including 404 Mg/ha increased unsaturated hydraulic conductivity. An additional doubling of the whey application rate, however, decreased the hydraulic conductivity at a potential of −60 mm.

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