Arid Soil Research and Rehabilitation, Volume 7, pp. 71–78
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0890-3069/93 $10.00 + .00
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Chemical Oxygen Demand Fate from Cottage Cheese (Acid) Whey Applied to a Sodic Soil

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Abstract *Cottage cheese (acid) whey is an effective amendment in sodic soil reclamation, but the high chemical oxygen demand (COD) of whey is of concern in land application. The objective of this research was to determine the fate of COD from cottage cheese whey applied to a sodic soil. Treatments of 0, 25, 50, and 100 mm (0, 20, 40, and 80 Mg COD ha^{-1}) of whey were applied to dry-unacclimated Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids) in greenhouse lysimeters. The COD from lysimeter leachate at 1 m depth was monitored. Ninety days after whey application, total accumulative leachate COD for 0-, 25-, and 50-mm whey applications was not significantly different. Leachate COD concentrations from the 100-mm application reached 37% (29 400 mg COD L^{-1}) of the applied whey COD. Twenty-eight days after whey treatment, infiltration was reduced in all whey-treated lysimeters, probably as a result of increased microbial activity. Barley (*Hordeum vulgare* *L. cv. Ludd) grain yield was 0.0, 0.0, 0.44, and 0.26 kg m^{-2} and total dry matter yield was 0.54, 0.72, 2.0, and 1.4 kg m^{-2} for the 0-, 25-, 50-, and 100-mm treatments, respectively. Salts and/or organic overloading appeared to inhibit initial barley growth in the 100-mm treatment. Results indicate a single 100-mm application to be excessive in terms of organic matter and/or salts.*

Keywords chemical oxygen demand, organic matter decomposition, food processing waste, land application, infiltration

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Received 28 May 1992; accepted 11 September 1992.

Introduction

Cottage cheese (acid) whey, a by-product of cottage cheese manufacture, contains about 50% of the original milk solids and up to 90% of the initial milk volume. U.S. creamed and low-fat cottage cheese production in 1991 was 366 000 Mg (U.S. Crop Reporting Board 1992), which equates to a cottage cheese whey production of approximately 3 × 10^6 Mg. Producers, especially small ones, find whey disposal costly because of changing state and federal disposal regulations and fluctuating market values for whey (House of Representatives 1979).

Cottage cheese whey has been applied to arid, high-pH sodic soils. The results show that acid whey application helps to reclaim sodic soils by lowering soil pH, exchangeable sodium percentage (ESP), and sodium adsorption ratio (SAR), and by improving aggregate stability and infiltration as well as crop yield (Robbins and Lehrsch 1992; Jones et al. 1993). The effects of land application of cheddar cheese (sweet) or casein whey on soil and crops have been studied by several researchers. Sharratt et al. (1962) and Peterson et al. (1979) showed that sweet whey applications increased crop production. Sharratt et al. (1962) found that a 25-mm depth of whey contains 370 kg N, 120 kg P, and 450 kg K ha^{-1}. Sharratt et al. (1959) and Peterson et al. (1979) showed decreased yields by excessive sweet whey applications and cited a 100-mm seasonal application as optimum. Soil aggregation increased by whey applications in proportion to the amount applied up to 85 mm.

Ghaly and Singh (1985) and Watson et al. (1977) concluded that in practical applications of from 25 to 32 mm there would be little chance for leaching of nitrates and other nutrients into groundwater. In another study, hydraulic conductivity decreased shortly after whey applications but returned to previous or higher values 1–3 weeks following whey treatment (McAuliffe et al. 1982; Watson et al. 1977).

Application of whey on land has the potential to induce a high oxygen demand in the soil. There are two measures of oxygen demand for wastewaters. Biochemical oxygen demand (BOD) indicates the oxygen equivalent of water-soluble and biodegradable organic matter, while chemical oxygen demand (COD) includes insoluble organic matter as well. Organic matter is found in many types of wastewaters and if improperly applied can cause odor problems as well as oxygen depletion in soil. Land application has been shown to be very effective in treating wastewater when organic overloading is avoided. McKinney (1962) showed that acclimated soils (those containing microorganisms ideally suited to the applied waste) have a more rapid uptake of oxygen than unacclimated soils. Sheaffer et al. (1979) showed that the availability of plant nutrients was affected by both sewage sludge loading rates and soil temperatures. Smith et al. (1977) measured COD concentrations from potato processing wastewater applied at five different sites for three years. Wastewater applications of 100 mm were applied at 1-, 2-, and 4-week intervals. One-week intervals were found to be excessive and a 4-week interval was recommended. Annual applications of potato processing wastewater added from 10 to 85 Mg COD ha^{-1}. Average wastewater COD concentrations ranged from 765 to 3080 mg COD L^{-1}, with maximum values ranging from 1040 to 7400 mg COD L^{-1}. Average COD removal efficiencies at a 1500-mm depth ranged from 95 to 98% and removal efficiencies based on maximum COD values ranged from 80 to 98%. In another study, annual sugarbeet processing wastewater applications added from 8 to 140 Mg COD ha^{-1} (Smith and Hayden 1983). Upper loading rates of 140 and 61 Mg COD ha^{-1} produced anaerobic soil conditions and damaged vegetation. Average COD concentrations ranged from 2000 to 8200 mg COD L^{-1}, with annual average removal efficiencies ranging from 48 to

84%. Comparison of the diluted wastewater COD concentrations from these studies with a cottage cheese whey COD of 68 000 mg COD L^{-1} (Gilliland 1979) exhibits thc potential problem of overloading the soil with organic matter from whey application.

The objective of this research was to determine the fate of the chemical oxygen demand from cottage cheese whey applied to a sodic soil in greenhouse lysimeters.

Materials and Methods

A lysimeter study was conducted in a semi-temperature-controlled greenhouse (15–35 °C) with supplemental lighting from 6:00 am to 10:00 am to compensate for early morning shading. To monitor weight changes due to irrigation, evapotranspiration, and drainage, each lysimeter had a hydraulic weighing system (Robbins and Willardson 1980). Each lysimeter contained 30 mm of 0.06-mm washed silica sand in the bottom to facilitate drainage. The lysimeters were filled with Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids) sodic surface soil (0–150 mm), from southern Idaho, which had not previously been irrigated or cultivated. The soil, which had been stored in containers since 1987, was sieved through a 6-mm screen and placed on top of the sand layer to a depth of 0.85 m. More of the same soil was obtained from the field on 10 June 1991, and an additional 0.15 m was added to each lysimeter. The dry soil columns were settled to a depth of 1.00 m at a bulk density of 1.4 Mg m^{-3} by vibrating the sides of the lysimeters. Each lysimeter had a surface area of 0.072 m^2 and a pore volume of 33 L or an equivalent of 455 mm of water depth.

Cottage cheese whey was obtained from Dairy Gold, Inc. in Twin Falls, Idaho, where the milk acidification process used an equivalent of 3 g of phosphoric acid (H_3PO_4) per kilogram milk. The whey contained 21 mmol Ca, 4 mmol Mg, 16 mmol Na, and 42 mmol K kg^{-1} whey and had an SAR of 3, pH of 3.3, and EC of 7.7 dS m^{-1}. The COD of whey applied to the lysimeter soil averaged 79 000 mg L^{-1} and the COD of the subsequently applied irrigation water was approximately 8 mg L^{-1}. Soil loading rates from the 0-, 25-, 50-, and 100-mm whey treatments were equivalent to approximately 0, 20, 40, and 80 Mg COD ha^{-1}, respectively. Treatments of 0-, 25-, 50-, and 100-mm whey were applied to the soil columns on day 0 (11 June 1991), each randomly replicated three times.

Whey treatments were applied and allowed to soak in. Six days later, the top 150 mm was removed, dried, thoroughly mixed, and returned to its respective lysimeter and settled to the previous density. All lysimeters then received 85 mm (6 L) of preplant irrigation. Each lysimeter was planted on day 7 with 15 barley (*Hordeum vulgare* L. cv. Ludd) seeds and later thinned to 11 plants per lysimeter. Barley was harvested during the twelfth week of growth. Irrigations were applied using fresh water at volumes of 6, 10, 10, 5, and 10 L on days 6, 16, 28, 34, and 41 following whey application. Thereafter, on days 48, 55, 62, 69, 76, and 83, irrigation was applied at a rate of 1.25 times water loss due to evapotranspiration. To improve crop growth, 10.0 g of urea were applied to each lysimeter on day 62. Because of an aphid infestation, 0.5 g of Temik granules were applied to each lysimeter on days 41 and 43.

Leachate samples for COD determination were collected from the lysimeter drain tubes. From day 30 (first leachate) to day 55, leachate samples were collected each day drainage took place. Samples were then taken from the first leachate that appeared following each weekly irrigation. These samples were frozen until a sufficient number were collected to warrant analysis. The COD was measured using the dichromate reflux method (American Public Health Association et al. 1971). The 1971 procedure was followed instead of the more recent procedure due to the availability of equipment.

Results and Discussion

The accumulative leachate COD plot (Fig. 1) for the four treatments shows a marked difference between the slope of the 100-mm treatment and the other three treatments. The slope of each curve indicates COD removal efficiency, with a zero slope being 100% efficient. At 0.2 pore volumes the 100-mm curve differed significantly ($p = 0.05$) from the other three curves. Accumulative values and COD concentrations of replication 2 were three to four times higher than those from replications 1 and 3, which might suggest water flow between the lysimeter wall and soil column. Data from the second replication were therefore not used in producing the 100-mm curve. Plotting accumulative leachate COD against leachate volume rather than time produced a higher correlation for each of the four treatments. This was due to the variation of time between leachate accumulation and sample collection.

Using the 0-mm values as background, net COD removal efficiencies at the 1-m soil depth for the 25-, 50-, and 100-mm treatments were calculated from the data in Table 1. Accumulative 90-day removal efficiencies were 99, 96, and 90% and at 0.2 pore vol-

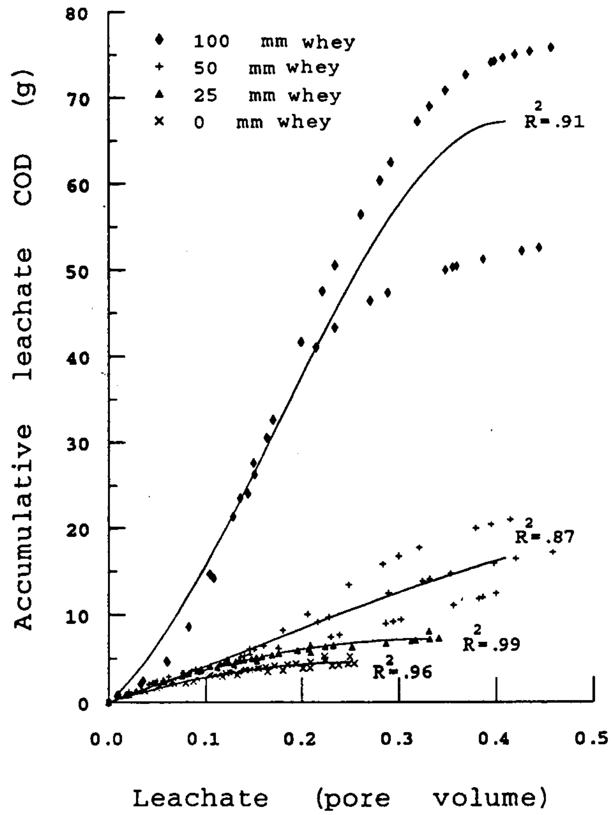

Figure 1. Accumulative leachate drainage water COD as a function of leachate volume and whey treatment.

Table 1
COD of Applied Whey and Total Accumulative Leachate as Well as Average, Maximum, and Minimum Sample COD Values for Four Whey Treatments Applied to a Freedom Silt Loam Soil

Whey Depth (mm)	Applied Whey COD (g)	Accumulative 90-Day Leachate COD (g)	Leachate COD ($mg\ L^{-1}$)		
			Average	Maximum	Minimum
0	0	5.4 a	686 a	1180	254
25	146	7.4 a	1030 a	1460	282
50	291	17.4 a	1230 a	2380	602
100	582	64.7 b[a]	7320 a	29400	491

Note. Numbers in the same column followed by the same letter are not significantly different at the $p = 0.05$ level ($n = 3$).
[a]Replication 2 data not used in deriving this value.

umes removal efficiencies were 99, 99, and 94% for the 25-, 50-, and 100-mm treatments, respectively. Average sample COD concentrations for whey treatments of 25, 50, and 100 mm were 0.44, 0.69, and 8.4%, and maximum sample COD concentrations were 0.36, 1.5, and 36% of the applied whey COD (79 000 mg L^{-1}). Minimum COD values occurred for the 0- and 25-mm treatments prior to day 90, while the 50- and 100-mm treatment values were still declining on day 90, indicating that whey organic matter was continuing to be leached from the 50- and 100-mm treatments.

Initial oxygen uptake in the soil was probably retarded by the dry-unacclimated soil condition (McKinney 1962). The rate of organic matter decomposition in the greenhouse soil temperatures would be expected to be greater than decomposition rates at lower field soil temperatures. Since leachate drainage for all lysimeters appeared between day 30 and day 55, at least 30 days of organic matter decomposition occurred before any leachate measurements were made. These facts limit application of data to field conditions where moisture content, soil acclimatization, and temperature variables will be significantly different.

Soil loading rates for the 25-, 50-, and 100-mm whey treatments were 20, 40, and 80 Mg COD ha^{-1}, respectively. These rates are within the range of upper daily and weekly loading rates found in the literature. Jewell and Loehr (1975) found that a daily loading rate of 17.9 Mg COD ha^{-1} did not overload an acclimated soil. Smith (1974) showed peak weekly decomposition of 8 and 2.5 Mg ha^{-1} of COD for loading rates of 112 and 11.2 Mg ha^{-1}, respectively.

Cumulative infiltration of the final 120 mm of a 150-mm irrigation, 28 days after whey application, is shown in Fig. 2. Total infiltration time for 120 mm of water applied to the 25-, 50-, and 100-mm treatments was 320, 430, and 420% of the 0-mm treatment, respectively. Lower infiltration rates were attributed to the abundance of microbial activity due to whey organic matter, warmer greenhouse soil temperatures, and soil moisture levels near field capacity. In a sodic soil under field conditions, Jones et al. (1993) showed infiltration time for whey treatments of 25, 50, and 100 mm were 33, 31, and

26% of a 0-mm treatment 53 days after whey application. The field soil was allowed up to 4 weeks resting time between irrigations while this soil was irrigated weekly.

Barley grain yield for the 50-mm treatment was significantly greater than for the 0- and 25-mm treatments where kernels did not mature (Table 2). Grain yield for the 100-mm treatment was 59% of the 50-mm yield. Barley dry matter yield (grain + straw) for the 25-, 50-, and 100-mm treatments was 130, 370, and 260% of the 0-mm treatment yield, respectively. Yield from the 50-mm treatments differed significantly from the 0- and 25-mm treatments. Initial plant growth was slowed in the 100-mm treated lysimeters, probably by salts and/or organic overloading.

Conclusions

The results of this study indicate that the chemical oxygen demand concentration in cottage cheese (acid) whey must be considered in land application. While increased microbial activity from whey organic matter may temporarily decrease infiltration rate, given adequate resting periods, whey application greatly improves infiltration. Crop yield is improved by whey application if COD or salt overloading does not inhibit growth. Depth of application should be limited by organic loading of soil and possible groundwater contamination from nitrates and other nutrients. This study showed that

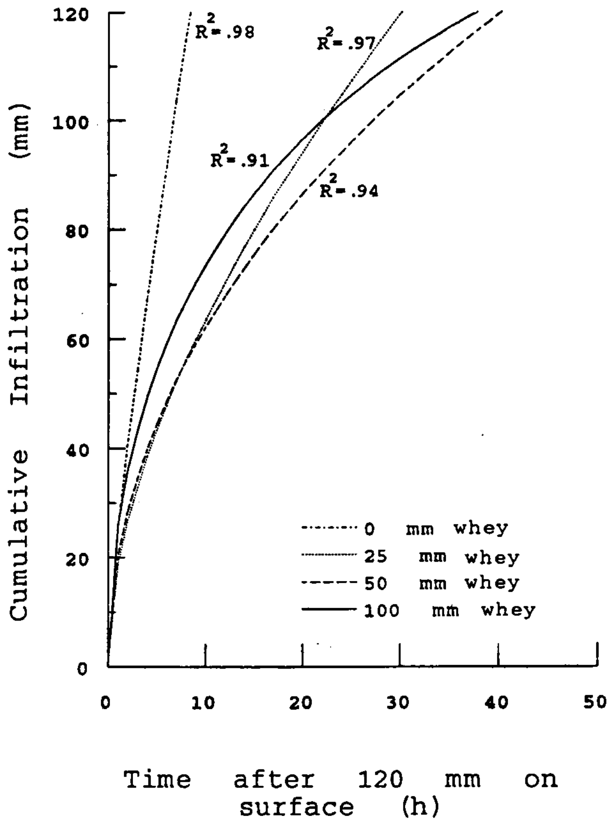

Figure 2. Cumulative infiltration of the final 120 mm of a 150-mm irrigation as a function of time and whey treatment in a Freedom silt loam.

Table 2
Lysimeter Barley Yields of Grain and Total Dry Matter

Whey Depth (mm)	Yield ($kg\ m^{-2}$)	
	Grain	Dry Matter
0	0.0[a] a	0.54 a
25	0.0 a	0.72 a
50	0.44 b	2.04 b
100	0.26 ab	1.43 ab

Note. Numbers in the same column followed by the same letter are not significantly different at the $p = 0.05$ level ($n = 3$).
[a]Barley kernels did not mature in the 0- and 25-mm treatments.

neither a single 25- or 50-mm whey application (20 or 40 Mg COD ha^{-1}) was excessive in terms of the leachate COD at a 1-m depth. The heavy chemical oxygen demand of a 100-mm application was excessive in greenhouse lysimeters. Based on other studies that considered leaching of nitrates, a recommended safe annual whey application is 32 mm. Further study under field conditions is warranted to observe the fate of COD under more natural conditions and through seasonal applications. The nitrates as well as organic matter from whey and their relationship to each other might also be considered.

Acknowledgment

This work was supported in part by the Western Dairy Foods Research Center.

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