HANDBOOK OF SOIL CONDITIONERS

SUBSTANCES THAT ENHANCE THE PHYSICAL PROPERTIES OF SOIL

EDITED BY

ARTHUR WALLACE
University of California–Los Angeles, and
Wallace Laboratories, El Segundo, California

RICHARD E. TERRY
Brigham Young University
Provo, Utah

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Cheese Whey as a Soil Conditioner

Charles W. Robbins and Gary A. Lehrsch *Agricultural Research Service, U.S. Department of Agriculture, Kimberly, Idaho*

I. WHEY PRODUCTION, COMPOSITION, AND CHARACTERISTICS

Whey is the liquid by-product of cheese and cottage cheese manufacture from milk. Each kg of cheese produced results in the production of about 9 kg of whey. In 1993, the U.S. cheese and cottage cheese industry produced approximately 23×10^6 m^3 (6×10^9 gal) of whey (National Agricultural Statistics Service, 1994). Most of this is used directly as livestock feed or concentrated or dehydrated and used in human food and animal feed manufacture. Depending on the locality and economic factors, 20 to 100% of the whey produced is applied for beneficial effects on soils, or is land applied as a disposal procedure.

Fresh whey composition varies depending on the cheese manufacture process used (Table 1). Most cheeses are made by biological culture processes that coagulate the milk proteins, and the resulting whey is often called "sweet" whey. Some cottage and creamed cheeses are made by coagulating the milk proteins using an equivalent of 3 g H_3PO_4 per kg of milk, and the resulting whey is often called "acid" whey. Sodium chloride is also added in some cheese-making processes. Even without salt or acid additions, whey is very salty due to the salts that come from the milk.

Ryder (1980) discusses eleven useful whey byproduct separation methods that separate usable carbohydrates or proteins from the liquid phase. Most of these processes still produce large volumes of liquid waste with essentially the same mineral composition as fresh whey. As a consequence of differences in methods, whey and these other wastes vary in composition somewhat from one

Table 1 Typical Fresh Whey Composition

	Sweet Whey	Acid Whey
Water	92%	92%
Total solids	8%	8%
COD[a]	5–7.5%	5%
pH	3.8–4.6	3.3–3.8
Electrical conductivity	7–12 dS m^{-1}	7–8 dS m^{-1}
	mg kg^{-1}	
Total nitrogen	900–2200	900–2200
Total phosphorus	300–600	1100
Calcium	430–1100	840
Magnesium	90–120	100
Sodium[b]	360–1900	600
Potassium	1000–1400	1000–1400
SAR[b]	4–16	3–4

[a] COD is the chemical oxygen demand.

[b] The sodium concentration and the sodium adsorption ratio (SAR) vary with the amount of salt used in the various cheese manufacturing processes and the fraction that ends up in the whey.

type of cheese to the next as well as the subsequent wastes generated by processing whey to remove butterfat, lactose, or casein for other uses.

Whey is mostly water with only about 8% solids. It is a mild acid with high soluble salt, COD (chemical oxygen demand), and fertilizer nutrient contents compared to most waste waters. Because of these traits, cheese whey is a potential soil amendment or conditioner for many soils if the distance from the production plant to the use site is minimal. If applied in excess, whey can decrease soil productivity and cause environmental degradation.

II. WHEY AS A PLANT NUTRIENT SOURCE

A 10 mm deep (100 m^3 ha^{-1}) whey application applies 90 to 220 kg N ha^{-1}, 30 to 60 kg P ha^{-1} from sweet whey, about 110 kg P ha^{-1} from acid whey and 100 to 140 kg K ha^{-1}, using the concentrations from Table 1.

The main disadvantage of using whey as a fertilizer source is the cost of transporting a material that is 92 to 93 percent water and contains less than 2.5 kg N Mg^{-1} (5.6 lb N ton^{-1}), 0.3 to 1.1 kg P Mg^{-1} (0.7 to 2.5 lb P ton^{-1}) and 1.0 to 1.4 kg K Mg^{-1} (2.2 to 3.1 lb K ton^{-1}) of whey. Unless the cheese manufacturer is willing to accept most of the transportation costs as a whey disposal cost, whey as a fertilizer, or any other amendment for that matter, is not economical. A second disadvantage of using whey as a fertilizer is that whey is produced on a year-round basis. Many crop uses of whey are limited to seasonal application conditions, especially where very wet or frozen soil conditions exist for part of the year. On the other hand, successful year-round application systems have been developed where application rates have been limited to crop fertilizer needs and more than one crop type is treated throughout the year from a particular cheese plant.

The fertilizer value and use potential of whey has been recognized for some time and has been demonstrated on acid soils in high to moderate rainfall areas in Scotland (Berry, 1922), New Zealand (Radford et al., 1986), Nova Scotia (Ghaly and Singh, 1985), Michigan (Peterson et al., 1979), and Wisconsin (Sharratt et al., 1962; Watson et al., 1977). The plant nutrient benefits of land applied whey have more recently been demonstrated on calcareous soils in the 7.6 to 8.8 pH range under irrigation in an arid climate (Robbins et al., 1996; Robbins and Lehrsch, 1992).

Nitrogen in fresh whey is present primarily as proteins, however, nitrate measurement in field soils and laboratory column soils receiving 50, 100, 200, and 300 mm deep applications of whey to a Miami silt loam in Wisconsin showed that under aerobic conditions the organic nitrogen was readily converted to nitrates by soil microflora (Sharratt et al., 1962). The initiation of conversion to nitrate was measured within two weeks of application and continued throughout the first corn (*Zea mays* L.) growing season. Nitrates continued to be produced at reduced rates during the second corn growing season. The nitrification rate appeared to be controlled by the carbon:nitrogen ratio of the whey and treated soil.

Fresh cottage cheese acid whey applied in sodic soil reclamation studies (Jones et al., 1993b) contained 79% ortho-P and 21% organic P. Fresh sweet whey from a plant making swiss and mozzarella cheese used in a whey land disposal study (Robbins et al., 1996) contained 58% ortho-P and 42% organic P. Fresh whey samples collected in 1994 from a cheddar type hard cheese plant, a processed cheese plant, and a plant that produces creamed and mozzarella cheese all contained about 63% ortho-P and 37% organic P.

Acid whey was applied to two sodic soils by Jones et al. (1993b). The first soil was in field plots and the second soil was in greenhouse lysimeters. The acid whey contained an equivalent of 0.3% phosphoric acid on a wet basis and contained 1.05 g P kg^{-1} whey. One-time 0, 25, 50, and 100 mm deep (0, 250, 500, and 1,000 m^3 ha^{-1}) whey applications added 263, 525, and 1,050 kg P ha^{-1}. After the whey infiltrated into the soil, 100, 75, 50, and 0 mm of water was applied to the respective treatments to bring all treatments to the same water content. Seven days later the soil surfaces were tilled to mix the whey into the upper 0.10 m of soil. They were then planted to barley (*Hordeum vulgare* L. cv. Ludd) and irrigated, as needed, until the barley matured.

Table 2 Bicarbonate Extractable ortho-P Concentrations in a Cottage Cheese (Acid) Whey Treated Calcareous Freedom Silt Loam Soil in Greenhouse Lysimeters

Whey (mm)	Total P added (kg ha^{-1})	P extracted (mg P kg^{-1})			
		0–0.15 m	0.15–0.30 m	0.30–0.60 m	0.60–0.90 m
0	0	4.9 a	4.8 a	5.0 a	6.2 a
25	263	14.1 b	6.8 a	4.1 a	5.2 a
50	525	28.9 c	10.2 ab	5.5 a	6.0 a
100	1050	29.6 c	11.5 b	6.3 a	6.8 a

Numbers in a column followed by the same letter are not different at the $P \leq 0.05$ level.

The first part of the study consisted of applying these treatments to a slightly sodic (sodium adsorption ratio (SAR) of 13.3, pH of 8.2, and saturation paste extract electrical conductivity $(EC)_{se}$ of 1.1 dvSm^{-1}) Freedom silt loam (fine-silty, mixed, Xerollic Calciorthids) soil in greenhouse weighing lysimeters (1.0 m deep by 0.30 m diameter, Robbins and Willardson, 1980). The four treatments were randomly replicated three times. The initial bicarbonate extractable ortho-P concentrations (5 mg P kg^{-1} soil) were very low (Table 2). The lysimeter soils were irrigated at a 0.25 leaching fraction until the barley had matured and 0.5 pore volumes of water had drained from the bottom of each lysimeter. At 104 days after planting, the soils were sampled at 0–0.15, 0.15–0.30, 0.30–0.60, and 0.60–0.90 m depth increments. The 0.5 M $NaHCO_3$ extractable PO_4-P concentration in each depth increment was determined using an ascorbic acid method (Watanabe and Olsen, 1965) (Table 2). In the second study (same treatments as the first), treatments were applied to a saline-sodic (SAR of 21, pH of 8.8, and EC_{se} of 27 dS m^{-1}) Declo loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids) soil in 2.0 by 2.0 m field basins. The bicarbonate extractable ortho-P was initially very low (2 to 4 mg P kg^{-1} soil) throughout the sampled profile (Table 3). The four unreplicated treatments were randomly located in a previously nonirrigated grazed range site. Four 150 mm flood irrigations were applied to the basins during the barley growing season.

After the barley matured (59 days after planting), four samples were taken from each basin at 0–0.01, 0.01–0.05, 0.05–0.15, 0.15–0.25, 0.25–0.50, 0.50–0.75, and 0.75–1.00 m depth increments and air dried. The bicarbonate extractable ortho-P concentration in each of the four samples at each depth increment was determined as described above. The study methods are described in greater detail in Jones et al. (1993b).

In the greenhouse study, the bicarbonate extractable ortho-P concentrations were increased in the surface 0.15 m by all whey applications and by the 525 and 1050 kg P ha^{-1} treatments in the 0.15–0.30 m depth increment (Table 2). Below 0.30 m, the bicarbonate extractable ortho-P concentrations were not sig-

Table 3 Bicarbonate Extractable ortho-P Concentrations at Different Depths in a Cottage Cheese (Acid) Whey Treated Saline Sodic Declo Loam Field Soil

Whey (mm)	Total P added (kg ha^{-1})	P extracted (mg P kg^{-1})						
		0.0–0.01 m	0.01–0.05 m	0.05–0.15 m	0.15–0.25 m	0.25–0.50 m	0.50–0.75 m	0.75–1.00 m
0	0	3.8 ± 0.6	4.0 ± 0.2	4.0 ± 0.6	3.6 ± 0.6	2.2 ± 0.7	2.1 ± 0.6	2.9 ± 0.6
25	263	12.2 ± 1.4	13.8 ± 0.8	11.2 ± 2.2	5.9 ± 0.6	2.4 ± 0.6	1.7 ± 0.2	3.0 ± 0.4
50	525	28.3 ± 4.5	32.0 ± 1.6	13.4 ± 3.5	8.3 ± 1.9	3.5 ± 2.1	2.5 ± 1.3	3.3 ± 0.9
100	1050	30.4 ± 1.2	28.1 ± 3.5	15.5 ± 5.8	10.2 ± 1.1	5.9 ± 0.7	4.9 ± 0.1	4.3 ± 1.5
	Initial pH	8.5	8.5	8.5	8.8	9.6	9.7	9.9

Each value shown is the mean of four samples taken at each depth from a single nonreplicated plot.

nificantly changed. In the field plots, the bicarbonate extractable ortho-P concentrations were increased in the surface 0.25 m by all whey application rates (Table 3). There also appears to be a slight increase for the 1050 kg P ha^{-1} treatment down to at least 0.75 m.

The 25 mm whey treatment increased the bicarbonate extractable P to adequate levels of these two very low P soils down to a depth of 0.15 m. It appears that the 50 and 100 mm treatments, upon mixing in the 0.15 to 0.30 m depths, would also bring the surface 0.30 m of soil up to adequate P fertility levels. It does not appear that sufficient P is moving below 0.5 m to be of environmental concern, even though 21% of the original P was in organic forms.

Measurement of saturation extract K movement and exchangeable K changes in acid and calcareous soils suggest that whey K is either mostly inorganic or that it is rapidly released from organic compounds upon whey application to soils and the K becomes readily involved in cation exchange and adsorption reactions (Peterson et al., 1979; Robbins et al., 1996). Trace element concentrations of Al, Fe, B, Cu, Zn, Mn, and Cr are essentially that of whole milk and are too dilute to be of plant nutrient value at reasonable whey application rates (Peterson et al., 1979).

When whey was applied to a Wisconsin Miami silt loam at 0, 50, 100, 200, and 300 mm depth increments on field corn plots, the maximum stover and grain yields were achieved with the 50-mm application the first year after whey additions (Table 4) (Sharratt et al., 1962). The 200-mm whey application produced the greatest stover production the second year, while the 300-mm whey application produced the highest grain yield. Both stover and grain yields de-

Table 4 Effects of Applying Whey to a Miami Silt Loam in the Spring of 1959 on Corn Stover and Grain Yield and Soil Salinity at Planting in 1959 and 1960

Whey added[a] (mm depth)	Corn stover[b] (kg ha^{-1})		Corn grain[b] (kg ha^{-1})		Saturation extract EC (dS m^{-1})	
	1959	1960	1959	1960	1959	1960
0	4030	3070	4870	3930	1.1	1.1
50	6600	5020	7260	5730	3.0	1.8
100	6520	5730	7050	6340	4.4	2.1
200	5870	6920	6630	6620	5.1	3.1
300	5470	6518	6400	7060	6.5	3.5

[a] Each 100 mm of whey added 740 kg N ha^{-1}, 250 kg P ha^{-1}, and 900 kg K ha^{-1}.

[b] Average of duplicate plots.

Source: Adapted from Sharratt et al., 1962.

creased the first year when more than 50-mm of whey was applied and the stover decreased on the 300-mm treatment the second year. Prior to the first planting after the whey application, the saturation extract EC values were drastically increased by the whey additions and were still elevated at the time of the next planting date. Corn forage yield reduction due to soil salinity starts at an EC of about 3 dS m^{-1}, and corn grain yield starts to decrease at an EC of about 2.5 dS m^{-1} (Bresler et al., 1982). Additionally, seedlings are usually more salt sensitive than plants at later growth stages. The yield decreases at the higher whey application rates appear to be salinity induced (see Section VIII). The corn grain N, P, and K concentrations continued to increase with increased whey application rates, even though yields decreased at the higher whey rates (Table 5).

Phosphorus and K leaf concentrations continued to increase with increased whey application on Plano silt loam in Arlington, Wisconsin, when 0, 100, 200, 400, and 800 mm of whey was applied prior to the first crop in a five-year whey treatment study (Peterson et al., 1979). The maximum corn yields were produced with the 200-mm whey rate for the first three years, and the 800-mm whey rate produced the greatest yields the fourth and fifth years. The 100-mm treatment increased the corn yields 2.5, 2.2, 2.2, 1.7, and 2.0 times that of the untreated plots for the first through fifth years of the study. The 200-mm whey plot yields were only slightly greater than the 100-mm plot yields.

These two studies were intended as whey disposal method evaluations and show that approximately 50 to 100-mm (500 to 1000-m^3 ha^{-1}) whey applications provide the needed plant nutrients for maximum crop yields on soils in rainfed crop areas. Neither study gave any soil pH data or indicated whether lime had been applied to the soils.

Table 5 Effects of Whey Nutrients Applied to a Miami Silt Loam in the spring of 1959 on the N, P, and K Contents of Shelled Corn Grown in 1959 and 1960

Whey	Added nutrients (kg ha^{-1})			Nitrogen (g kg^{-1})		Phosphorus (g kg^{-1})		Potassium (g kg^{-1})	
(mm)	N	P	K	1959	1960	1959	1960	1959	1960
0	0	0	0	14.2	13.0	2.4	2.2	3.3	2.9
50	740	250	900	15.9	15.5	3.2	3.2	3.4	3.4
100	1480	490	1790	16.6	15.9	3.3	3.3	3.4	3.3
200	2960	990	3590	17.9	17.2	3.5	3.5	3.6	3.5
300	4430	1480	5370	18.4	16.7	3.5	3.5	3.7	3.5

Source: Adapted from Sharratt et al., 1962.

III. WHEY AS AN AMENDMENT FOR SODIC AND SALINE-SODIC SOILS

Salt affected soils are categorized as normal, saline, sodic, and saline-sodic (Bresler et al., 1982; Robbins and Gavalak, 1989) (see Chapters 7, 8, 9). Normal soils, in this context, are those soils that do not contain sufficient soluble salts or a sufficiently high exchangeable sodium percentage (ESP) or sodium adsorption ratio (SAR) to limit plant growth of salt or high pH sensitive plants. Saline soils contain sufficient soluble salts in the upper root zone to reduce yields of most cultivated or ornamental plants. Total soluble salts are estimated by measuring the electrical conductivity (EC) of saturated soil extracts (Robbins and Wiegand, 1990). A soil with an EC greater than 2 to 4 dS m^{-1} (depending on soil type and plants grown) is considered to be saline due to salt effect on growing plants. Sodic soils have saturation extract ECs less than 2 to 4 dS m^{-1} but have sufficiently high ESPs to destroy soil structure, which in turn reduces aeration and water infiltration rates. When the SAR or ESP values exceed 10 to 15 (depending on soil texture, clay type, and irrigation method), soil physical properties deteriorate, and the soils are said to be sodic. Saline-sodic soils have ECs greater than 2 to 4 dS m^{-1} and SAR or ESP values greater than 15 or 13, respectively. Saline-sodic soils limit plant growth due to high soluble salts; however, if they are leached with low salt water, they will convert to sodic soils with the associated poor physical characteristics.

Because of the high soluble salt concentration in whey, whey should not be applied to saline soils or to normal soils with shallow water tables. Whey should be applied sparingly (25 mm $year^{-1}$) where salt sensitive crops are to be grown (see Bresler et al., 1982, or Robbins and Gavlak, 1989, for salt sensitivity data).

Acid wheys and sweet wheys that contain less than 1000 mg Na kg^{-1} (SAR less than 10) are ideal for reclaiming sodic and saline-sodic soils. These wheys are mild acids that will lower the soil pH by neutralizing soil solution carbonates and bicarbonates and consequently increase the solubility of calcium carbonates (lime) which, in turn, decreases the soil SAR and ESP (Robbins 1985). Whey contains about 5% readily decomposable organic matter (measured as chemical oxygen demand of COD), and its decomposition contributes to the lowering of soil pH by generating additional organic acids and mineralization of nitrogen to nitrate. All wheys are rich in Ca, Mg, and especially K, relative to the Na concentrations, and will replace the exchangeable Na, thus decreasing the SAR and ESP (Robbins, 1984). The high ionic concentration in whey also acts as a flocculating agent in sodic soils, increasing infiltration rates and allowing the Na to be more readily leached from the root zone.

Acid whey applied to a sodic Freedom silt loam (fine-silty, mixed mesic, Xerollic Calciorthids) soil in leaching columns was shown to decrease pH and SAR while increasing aggregate stability (Table 6). The whey was applied at

Table 6 Whey Effects on pH, EC, SAR, ESP, and Aggregate Stability of a Sodic Freedom Silt Loam

Whey depth (mm)	pH	EC (dS m^{-1})	SAR	ESP	Aggregate stability (%)
		0–150 mm soil depth			
0	8.5 a	0.9 a	10.7 a	11.3 a	11 a
20	7.2 b	1.9 b	3.4 b	5.5 b	12 a
40	7.2 b	2.4 c	2.7 c	4.5 c	18 ab
80	6.7 c	3.8 d	1.9 d	2.6 d	22 b
		150–300 mm soil depth			
0	8.5 a	1.4 a	14.9 a	13.3 a	8 a
20	7.4 b	2.9 b	10.5 b	9.2 b	9 a
40	8.3 b	3.7 c	8.9 c	9.1 b	7 a
80	6.8 c	4.2 d	6.2 d	6.2 c	8 a
Original soil	8.3	3.8	16.3	14.9	

Numbers in the same column for the same depth increment followed by the same letter are not significantly different at the $p = 0.05$ level.
Source: Adapted from Robbins and Lehrsch, 1992.

0, 20, 40, and 80-mm depth (0, 200, 400, and 800 m^3 ha^{-1}) treatments. The 20 mm treatment reclaimed the surface 150 mm of soil and additional leaching with low EC, low SAR water, the 150–300 mm soil depth would be reclaimed by the 40 mm whey application, if not by the 20 mm application (Robbins and Lehrsch, 1992).

Jones et al. (1993b) treated saline-sodic Declo loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids) field plots at 0, 25, 50, and 100-mm whey depths (0, 250, 500, 1,000 m^3 ha^{-1}) (Table 7). The whey was applied and then tilled into the surface followed by planting barley (*Hordeum vulgare* L. *Ludd) and four irrigations with high-quality water. Leaching this soil with high-quality water, without any whey treatment, decreased the pH, EC, SAR, and ESP, but the process caused the soil surface to disperse and seal, reducing air and water entry. Addition of the whey prior to the first irrigation, plus the four irrigations, further reduced pH, EC, SAR, and ESP and increased the infiltration rate. The 50-mm whey treatment reclaimed the surface 50 mm of soil, while the 100-mm whey treatment reclaimed the soil down to at least 150 mm. The irrigation water used on this soil has an EC of 0.2 dS m^{-1} and an SAR of less than 0.5. Consequently, a one-time application of 100 mm of acid whey will permanently reclaim this surface soil. There is not a shallow water table associated with the salinity problem in this soil.

Table 7 Whey Effects on pH, EC, SAR, and ESP at Two Depth Increments and Time to Infiltrate 120 mm of Low EC (0.2 dS m^{-1}) Irrigation Water for a Saline Sodic Declo Silt Loam

Whey depth (mm)	pH	EC (dS m^{-1})	SAR	ESP	Time (h)
		10–50 mm			
0	8.5	1.3 b	9.5 c	11.0 e	54 b
25	8.1	0.9 a	3.7 b	7.9 b	18 a
50	8	1.8 c	3.6 b	5.9 a	17 a
100	7.7	1.2 ab	3.0 a	5.4 a	14 a
		50–150 mm			
0	8.2	1.4 b	9.3 c	9.6 b	
25	8	1.0 a	3.5 a	6.6 a	
50	8	2.1 b	6.0 b	8.6 b	
100	7.8	1.2 a	3.0 a	5.5 a	
Original soil	8.8	27	21	20	

Numbers in the same column for the same depth increment followed by the same letter are not significantly different at the P = 0.05 level.
Source: Adapted from Jones et al., 1993.

IV. WHEY EFFECTS ON AGGREGATE STABILITY

Adding whey decreases soil pH and increases Ca solubility. This, along with the soluble salts in the whey, increases the ionic strength of the soil solution, reducing the diffuse double-layer thicknesses next to the clay, and causes clay flocculation (Lehrsch et al., 1993). This improves aggregation and increases the soil's pore size distribution, allowing increased air and water movement within the soil profile (Hillel, 1982). Aerobic microorganisms that decompose lactose and whey proteins produce polysaccharides that help to stabilize these newly formed aggregates (Allison, 1968). Kelling and Peterson (1981) noted that most whey solids are milk sugars and proteins and are quite susceptible to microbial decomposition. The resultant products of such decomposition substantially improve soil aggregation and tilth.

Improvements in soil structure make soils easier to manage and less susceptible to erosion. As aggregation increases, more large pores (macropores) are formed throughout soil profiles. When these macropores occur at or near the soil surface, infiltration rates increase and runoff rates decrease. Watson et al. (1977) measured increased infiltration rates into a fallow soil about 3 months after sweet whey was surface applied. They attributed the infiltration increases to improved soil structure. Stable aggregates at the soil surface resist fracturing due to raindrop or sprinkler drop impact and slaking as water accumulates on the soil surface. Since fewer surface pores become obstructed with aggregate fragments and primary particles, infiltration rates decrease more slowly and runoff rates are kept relatively low. Low runoff rates minimize offsite sediment movement. As aggregate stability increases, erosion commonly decreases (Luk, 1979). Robbins and Lehrsch (1992) found that the aggregate stability of the uppermost 150 mm of a sodic, Freedom silt loam in laboratory columns doubled from 11 to 22%, when 80 mm of an acid whey was surface applied and incorporated (Table 6). In a subsequent study, Lehrsch et al. (1994) found aggregate stability to increase from 25% to 80% when 80 mm of acid whey was surface applied, and incorporated into sodium-affected soils.

From a soil management standpoint, larger soil aggregates are preferred over smaller ones. Sharratt et al. (1962) applied whey in the spring of 1959 and measured the aggregate size distribution in the 0.18 m plow layer in the fall of 1959 and 1960. The percent of aggregates with diameters >0.25 mm increased with whey application rate. In a field study, Kelling and Peterson (1981) found that the proportion of water-stable aggregates increased as whey application rates increased from 50 to 300 mm. In a greenhouse soil aggregate size distribution study, Kelling and Peterson (1981) found soil aggregation to improve as much from an application of 25 mm of whey (250 m^3 ha^{-1}) as from an application of 22.4 Mg ha^{-1} corn residue or 11.2 Mg ha^{-1} cow manure.

V. CONTROLLING FURROW EROSION IN IRRIGATED AGRICULTURE WITH WHEY

Furrow irrigation-induced erosion is a major problem threatening agricultural productivity in the western U.S. (Carter, 1993). A variety of techniques have been developed and are available to control this erosion (Carter, 1990; Lentz et al., 1992).

When Brown et al. (1996) applied whey to irrigation furrows in the spring prior to the first irrigation, furrow erosion was effectively controlled until the soil was disturbed by cultivation. They measured sediment losses from 91-m furrow lengths with 2.3% slopes that were untreated or treated with straw, whey or straw plus whey (Fig. 1). The whey was applied at about 200 l/min until about 300 l had flowed about 75% of the row length. The whey continued to flow to near the end of the furrow but did not leave the field. The plot area had been planted to sweet corn (*Zea mays* L.). Eight irrigations were applied during the growing season, and the soil was not cultivated after the treatments had been applied. Sediment loss during the eight irrigations for the whey alone was 14% that of the control, 16% for the straw alone, and less than 2% for the straw plus whey. If cultivation of weeds is necessary, the treatment effect is lost and the whey and/or straw must be reapplied to be effective. On shorter, steeper (4.4%)

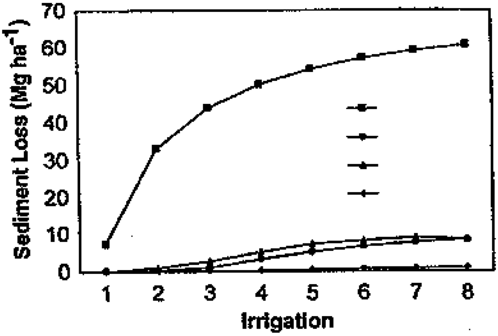

Figure 1 Sediment loss reductions from Portneuf silt loam as a result of treating furrows with whey (●), straw (▲), straw plus whey (◆), and check (■). (Adapted from Brown et al., 1996.)

slopes, the whey alone only reduced the sediment loss by one-third to one-half that of the control, while, straw plus whey still reduced the sediment loss to 3% that of the untreated furrows.

Whey's marked ability to decrease furrow erosion may be a consequence of its ability to increase aggregate stability (Lehrsch et al., 1994) and stabilize soil along wetted perimeters (Brown et al., 1996). When applied to the straw, the sticky nature of the whey also appears to cause the straw particles to stick together and to stick to the soil surface. Lehrsch et al. (1997) found that a single spring whey application increased a Portneuf silt loam's aggregate stability in the uppermost 15 mm of soil in furrow bottoms from 64% in control furrows to more than 83% in treated furrows by early July. These stability increases were correlated with measured decreases in furrow erosion. These research findings confirm what Kelling and Peterson (1981) had observed on acid soils, i.e., that whey-induced increases in aggregate stability (and infiltration) could significantly reduce both runoff and erosion.

VI. INFILTRATION AND HYDRAULIC CONDUCTIVITY CHANGES WITH WHEY APPLICATION

Depending on application rates, soil conditions, and time since last application, whey can increase or decrease infiltration and hydraulic conductivity rates.

Excessive whey applications may decrease infiltration rates and/or hydraulic conductivities in the short term owing to organic overloading. Barnett and Upchurch (1992) noted that high whey applications and the resulting organic matter loading on fine-textured soils caused rapid slime-producing bacteria growth which reduced infiltration rates. They recommended a 2 to 3 week rest period between whey applications for New Zealand soils. On these soils, 10–12 days were required for bacteria to decompose the whey and return the site infiltration rate to its previous rate prior to the next whey application. McAuliffe et al. (1982) measured saturated hydraulic conductivity decreases of 46% within 2 days after they applied 350 m^3 ha^{-1} of sweet whey (also in New Zealand). The hydraulic conductivities increased back to previous rates in 1 to 3 weeks after the whey was applied. Extreme whey applications may adversely affect hydraulic properties for long periods. Plots treated with 2000 m^3 sweet whey ha^{-1} in August 1972 and again in June 1973 by Watson et al. (1977) still had reduced infiltration rates into a dry Wisconsin prairie soil in the fall of 1974. Infiltration into wet soil was not reduced over the control by this date. Applications of 250, 500, and 1000 m^3 ha^{-1} of acid whey to a southern Idaho sodic Freedom silt loam in 0.3 m diameter by 1.0 m deep greenhouse lysimeters decreased infiltration rates measured 11, 27, and 53 days after whey application (Jones et al., 1993b). The lower infiltration rates appeared to be caused by increased microbial activity stimulated by the added organic matter and relatively warm soil conditions (Jones et al., 1993a).

Whey also affects infiltration rates measured under negative heads, that is, under tension. Infiltration measured at slightly negative water potentials (from -30 to -150 mm of water) excludes water flow through the largest soil pores, thus yielding a quantitative estimate of infiltration through the bulk of the soil matrix. Lehrsch and Robbins (1996) measured negative-head infiltration rates into a Portneuf silt loam following the harvest of a winter wheat crop that had been treated with whey during the growing season. They found that, as whey applications increased from 0 to 80 mm, infiltration rates at potentials of —60 and −150 mm decreased linearly, but slowly (Figs. 2 and 3). At these potentials, flow occurred only through pores with diameters of 0.5 mm or less. The decreases, most pronounced at the highest whey rate, were thought to be caused by organic clogging and microbiological activity. To maintain negative head infiltration at levels comparable to untreated conditions, they recommended that whey applications, if not incorporated, be limited to 40 mm during the growing season. Siegrist and Boyle (1987) suggest that the accumulation of organic material (particularly carbonaceous and nitrogenous compounds) reduce infiltration rates by clogging soil pores and that reducing the amount of organic material applied was necessary to avoid soil clogging.

Whey additions to soils have also been shown to increase infiltration rates when properly applied and managed. Watson et al. (1977) measured up to fourfold increases in infiltration rates (measured using a sprinkling infiltrometer) into a fallow Plano silt loam about 3 months after they surface applied up to 204 mm of whey. They attributed the marked infiltration increases to improved soil structure strength where whey was applied.

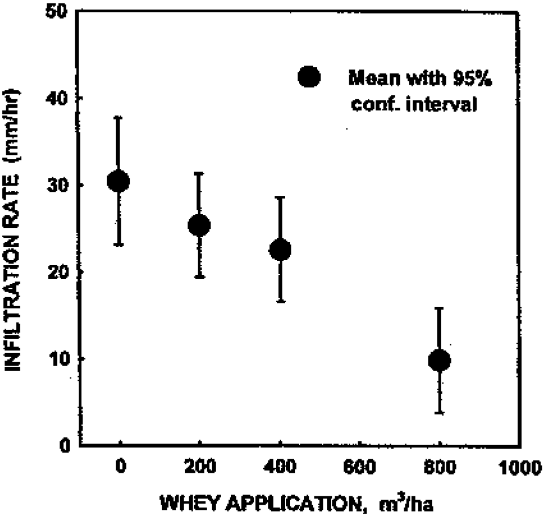

Figure 2 Infiltration rate at a water potential of −60 mm as a function of whey application. (Adapted from Lehrsch and Robbins, 1996.)

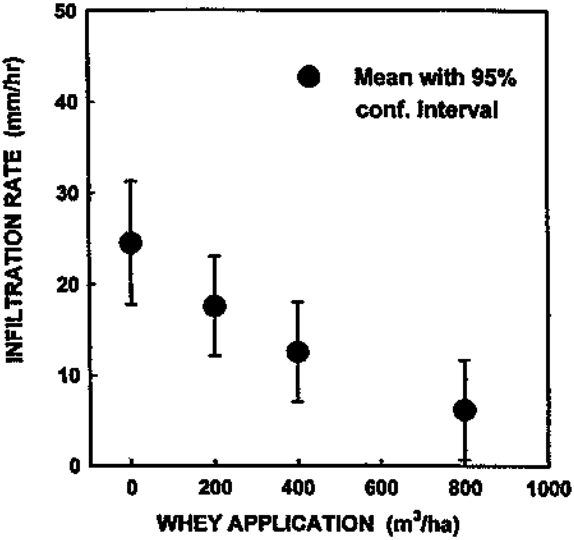

Figure 3 Infiltration rate at water potential of −150 mm as a function of whey application. (Adapted from Lehrsch and Robbins, 1996.)

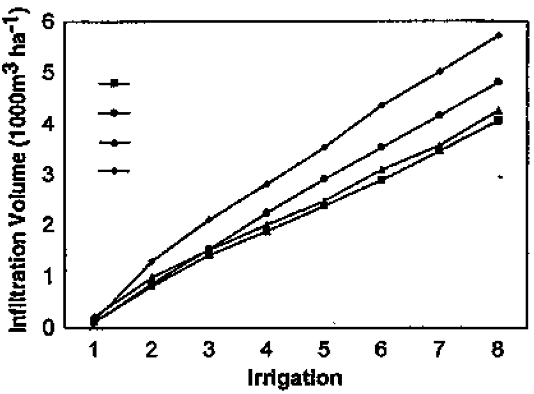

Figure 4 Cumulative infiltration after treating Portneuf silt loam soil furrows with whey (●), straw (▲), straw plus whey (◆), and check (■). (Adapted from Brown et al., 1996.)

Fifty-three days after saline-sodic, Declo loam field plots had been treated with whey, Jones et al. (1993b) measured faster infiltration of high-quality, low-EC (0.20 dS m^{-1}) water into the treated than into the untreated plots (Table 7). The higher infiltration rates were attributed to increased aggregate stability (Lehrsch et al., 1994; Robbins and Lehrsch, 1992) due to lower soil SAR and ESP as a result of the acid whey applications. They concluded that incorporating the whey, followed by an adequate resting period (about four weeks since the whey application), would increase infiltration rates.

Infiltration has also been measured into whey-treated irrigation furrows. Brown et al. (1996) increased furrow infiltration rates by treating furrows with whey, straw, and straw plus whey (Fig.4). Along the wetted perimeter of furrows not treated, a surface seal formed that limited infiltration. Upon drying, cracks appeared in the soil of the whey-treated furrows and remained for the rest of the season. Those cracks provided additional pathways through which irrigation water moved laterally and downward. The straw and straw plus whey placed in the furrows also increased seasonal infiltration.

VII. ENVIRONMENTAL CONCERNS ASSOCIATED WITH EXCESSIVE WHEY APPLICATIONS TO SOILS

As shown, cheese whey has the potential to improve chemical, physical, and possibly microbiological soil conditions. Whey, if applied in excess, also has the potential of degrading soils.

Whey contains between 50,000 and 75,000 mg COD kg^{-1} whey (Table 1) (26,000 to 40,000 mg Biological Oxygen Demand Kg $^{-1}$). When 50 mm or greater applications of whey have been applied to frozen or very wet soils that remain wet for 24 h or more, the authors have observed winter wheat kills and severe crop damage to potatoes, alfalfa, and barley. When Sharratt et al. (1959) weekly applied 0, 140, 290, 430, and 860 m^3 ha to an established alfalfa crop, only the 0 and 140 m^3 ha treated plants survived for three weeks on a soil with a pH of 6.7. The crop damage is due to rapid consumption of soil oxygen and rapid drops in redox potential to as low as −350 mV. This O_2 consumption is due to the oxidation of readily decomposable milk sugars and proteins. In excessive whey applications at a commercial disposal site, Fe and Mn have been solubilized to the extent of contaminating local domestic drinking-water wells. A 10-fold increase in corn leaf Mn and an 8-fold increase in corn leaf Zn concentration measured under 800-mm whey applications by Peterson et al. (1979) suggests that reduced soil redox potential solubilized considerable concentrations of these two metals and made them available for plant uptake and leaching.

Each mm (10 m^3 ha^{-1} of whey applied to the soil adds 400 to 600 kg total salt ha^{-1}. Another way of looking at the salt in whey is that whey would have to be diluted 1:20 with rainwater or distilled water to be considered of acceptable irrigation water quality. The effects of whey application rate on soil EC values are shown in Table 8 from the work of Sharratt et al. (1962). Both that paper and the paper of Peterson et al. (1979) show crop yield leveling off and then decreasing at and beyond 100-mm whey application rates due to increased soil salinity in high rainfall areas. In irrigated areas where soils or irrigation

Table 8 Effects of Whey on Soil EC of a (Miami) Silt Loam Soil Extract During the Two Growing Seasons Following Application

	Saturation extract EC (dS m^{-1}) at 25 C				
Date sampled[a]	Whey applied (mm)				
	0	50	100	200	300
4/20/59	1.20	1.15	1.20	1.20	1.20
5/26/59	1.15	3.00	4.40	5.10	6.45
9/20/59	1.05	1.95	2.10	3.45	3.95
5/27/60	1.10	1.80	2.05	3.05	3.50
9/29/60	1.00	1.65	1.95	2.30	2.50

[a] 4/29/59, before whey applied; 5/26/59, 16 days after whey application, just before corn planting; 9/20/59, at corn harvest; 5/27/60, before second corn planting; 9/29/60, at second corn harvest.

Source: Adapted from Sharratt et al., 1962.

water may contain marginal to excessive soluble salt concentrations, whey addition should proceed with caution when salinity is a concern, and soil salinity status should be monitored. Selection of salt tolerant crops (Bresler et al., 1982) should also be part of the management plan for all sites that receive more than 50 mm whey per year.

Acid whey application to a sodic soil effectively lowered the pH and increased its production (Jones et al., 1993b). The acid nature of whey can also adversely lower the pH of acid soils to the point of being injurious to crops. When sweet whey with a pH of 4.0 was added to an acid Spencer silt loam and a near neutral Miami silt loam, the pH of the acid soil was lowered sufficiently for a short period to be injurious to crops (Sharratt et al., 1959). The pH was also lowered in the neutral soil but not sufficiently to cause damage in most crops (Table 9).

When applying whey to irrigation furrows to minimize erosion, precautions should be taken. Because of whey's high COD (Jones et al., 1993a), it should never be released directly into surface waters without treatment. Watson et al. (1977) recommended that whey application rates be kept low enough to prevent runoff from entering surface water bodies. Kelling and Peterson (1981) were even more conservative when they recommended that whey be applied only to rough and/or residue-protected soil surfaces to minimize runoff and control erosion.

Table 9 Soil pH as Affected by Whey Application Rate and Time on Spencer and Miami Silt Loam Soils

Hours after initial application	Spencer silt loam[a]				Miami silt loam[b]			
	Whey applied (m^3 ha)							
	0	90	180	360	0	90	180	360
2	5.2	4.8	4.7	4.6	6.7	6.4	6.2	5.9
4	5.2	4.8	4.7	4.6	6.7	6.3	6.3	6.0
8	5.1	4.8	4.7	4.6	6.8	6.2	6.3	6.6
12	5.2	4.9	4.8	4.6	6.8	5.9	6.2	5.6
24	5.3	5.0	4.9	4.6	6.8	6.0	6.3	5.5
48	5.4	5.2	5.1	4.9	7.1	7.0	6.7	5.7
72	5.3	5.3	5.2	5.0	6.8	7.1	7.1	5.6
96	5.4	5.3	5.2	5.0	6.8	7.4	7.4	6.1
192	5.5	5.4	5.3	5.2	6.8	7.0	7.0	7.1

[a] Initial pH = 5.2, derived from granitic glacial till.

[b] Initial pH = 6.8, derived from limestone glacial till.

Source: Adapted from Sharratt et al., 1959.

VIII. ADDITIONAL RESEARCH NEEDS

Additional research is needed to better characterize the physical and hydraulic properties of soils treated with whey. Physical property changes occurring at and below the soil surface, though not well characterized to date, must be known to apply whey safely to soils for long periods of time. Further research should also examine the effects of whey, incorporated by tillage, on the physical and hydraulic properties of soil surfaces. A likely increase in aggregate stability after tillage (Lehrsch et al., 1994) may offset the infiltration reductions sometimes measured after whey additions.

Ghaly and Singh (1985) also cautioned that continuous applications of whey at high rates could contaminate groundwater with nitrate-N. In the laboratory, they added 32 mm of whey to soil columns. Thereafter, every eight days they applied 100 mm of simulated rainfall, representative of the May through September rainfall received at Halifax, Nova Scotia, Canada. The nitrate-N concentration in the leachate from columns 0.6 to 1.8 m deep ranged from 3.8 to 7.5 mg l^{-1} both 4 and 8 days after the whey was surface applied. Depending upon the climatic regime, irrigation needs, and hydraulic conductivity of the soil on the application site, the potential exists for nitrate-N to be leached from the soil profile to underlying groundwater.

Many crop uses of whey are limited to seasonal application conditions, especially where very wet or frozen soil conditions exist for part of the year. On the other hand, successful year-round application systems have been developed where application rates have been limited to crop fertilizer needs and different crops are treated throughout the year. As an example, hay or pasture sites are well suited to summer and fall whey application, row crops land is suited to winter and spring application, and winter grains are good crops for preplanting fall whey applications.

IX. CONCLUSIONS

Both sweet and acid wheys have been beneficially used to improve physical and chemical soil properties. Whey, especially acid whey, is an ideal amendment for sodic and saline-sodic soils if sodium chloride has not been added during manufacture of the cheese. Incorporated whey increases soil structure and aggregate stability. Whey applied to irrigation furrows, with or without straw mulch, prior to irrigation greatly reduces furrow erosion. Whey is rapidly decomposed when added to soils at moderate (up to 500 m^3 ha^{-1}) rates, and the N, P, and K from whey becomes available to crops within a few days to a few weeks of application. The disadvantages of using whey as a soil amendment or fertilizer include the high water content (92 to 95%), the high COD, and year-round whey production. The high water content limits its value in relation to transportation costs. The high COD limits the application rates to cold or wet soils. Some plant operators are reluctant to allow alternative whey use for short periods, such as soil application, if it interrupts continuous whey flow to livestock feeders or concentrating plants, even though the whey may be more economically disposed of as a soil amendment or fertilizer.

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