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Sodic Soil Reclamation Using Cottage Cheese (Acid) Whey

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Abstract *Cottage cheese production in the United States yielded approximately 3 × 10^6 Mg of cottage cheese (acid) whey in 1991. Unmarketable whey is disposed of in sewage treatment facilities or on land. Environmental concerns and new laws make disposal even more costly and difficult. While much whey is applied to land for fertilizer or disposal purposes, acid whey has recently been used as a sodic soil amendment. The objectives of this research were to determine the effects of whey application on chemical properties and infiltration rates of sodic soils. Four treatments of acid whey (0, 25, 50, and 100 mm) were applied to Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthids) in greenhouse lysimeters and to Declo loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids) in field basins. Accumulative sodium removal at 0.5 pore volumes of leachate was 1.0, 1.1, 1.2, and 1.7 mol for the 0-, 25-, 50-, and 100-mm lysimeter treatments, respectively. Whey applications lowered sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), and saturation paste pH in the lysimeter surface soil (0–150 mm) and field soil surface (10–150 mm). Saturated paste electrical conductivity was not significantly altered by whey application. In a greenhouse environment, 28 days after whey application, infiltration times in the 25-, 50-, and 100-mm treatments were 320, 430, and 420% of the 0-mm treatment, respectively. Infiltration times for field basin 25-, 50-, and 100-mm whey treatments were 33, 31, and 26% of the 0-mm treatment 53 days after whey application, respectively. 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. Excess salts and/or organic overloading in the 100-mm treatment appeared to inhibit initial plant growth. Results indicate that acid whey is effective in reclaiming sodic soil by lowering ESP, SAR, and pH and by improving infiltration.*

Keywords soil salinity, soil sodicity, soil reclamation, soil amendments, infiltration, hydraulic conductivity

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Introduction

Soils having an electrical conductivity (EC) less than 4 dS m^{-1} and a sodium adsorption ratio (SAR) greater than 13 are classed as sodic. High pH (>8.3) and high carbonate ion concentrations cause calcium to precipitate as $CaCO_3$. The factors of low EC, high SAR, and high pH increase soil dispersion and swelling, which leads to reduced permeability, crusting and poor tilth (Robbins and Gavlak 1989).

Effective methods of reclaiming sodic soils require cations (Ca^{2+}, Mg^{2+}, K^+) to replace Na^+ ions that are held on exchange sites. Bresler et al. (1982), summarized effective methods for reclaiming sodic soils such as applications of gypsum, high calcium–magnesium content salt water, sulfuric acid, or deep mixing or plowing to bring gypsum to the soil surface. Robbins (1986) showed organic matter additions and certain crops also to be effective in reclaiming sodic calcareous soils. Robbins and Carter (1983) showed that potassium readily replaces exchangeable Na^+ in many calcareous soils. Robbins and Lehrsch (1992) showed, in a column study, that cottage cheese (acid) whey was effective in reclaiming a sodic soil by lowering soil pH, SAR, and ESP to a depth of 300 mm.

The usefulness of acid whey in reclaiming sodic soils can be anticipated from the chemical properties of whey. One analysis of cottage cheese whey showed it contained 13 mmol Ca^{2+}, 5 mmol Mg^{2+}, 27 mmol Na^+, and 57 mmol K^+ L^{-1}, 9 g protein, and 36 g lactose kg^{-1}, and had a pH of 4.5 (Summers and Okos 1982). Reclamation would be expected by the presence of Ca^{2+}, Mg^{2+}, and K^+ ions, organic matter, and the acidity.

Each 10 L of milk used to make cottage cheese produces approximately 9 L of acid whey. U.S. creamed and low-fat cottage cheese whey production for the year 1991 was 366,000 Mg (U.S. Crop Reporting Board 1992) which equates to a whey production of over 3×10^6 Mg. Producers, especially small ones, often have difficulty marketing or disposing of the whey due to low prices and changing EPA disposal regulations (House of Representatives 1979).

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 sweet whey contains 370 kg N, 120 kg P, and 450 kg K ha^{-1}. Watson et al. (1977) showed that 25-mm applications produced little chance for leaching of nitrates and other nutrients into groundwater. Sharratt et al. (1959) and Peterson et al. (1979) showed decreased yields from excessive sweet whey applications and indicated a 100-mm seasonal application as optimum. Applications of more than 100 mm increased salt content sufficiently to temporarily inhibit plant growth. Soil aggregation benefitted from whey applications in proportion to the amount applied up to 85 mm.

McAuliffe et al. (1982) showed saturated hydraulic conductivity reductions of approximately 50% after two days with application of 36 mm of casein whey. Repeated applications caused hydraulic conductivity decreases of up to 99% in some soil cores. All soil core conductivities returned to previous or higher values 1–3 weeks after final whey applications were made. McAuliffe et al. concluded that to avoid conductivity reductions, an aerobic soil condition and a drying time interval between applications must be maintained, and the suspended solids should be removed. The study of Watson et al. (1977) confirmed that under anaerobic conditions, infiltration capacity decreased. Several months after applications of 100 and 200 mm of whey, water infiltration rates were greater by as much as four times on both wet and dry fallow prairie soils. In these studies, sweet whey (pH $\approx$ 6.3) or casein whey was applied to acidic soils (pH $<$ 7).

The objectives of this research were to determine the effects of acid whey application to the salt balance, pH, exchangeable cation ratio profile, and infiltration rates of sodic soils. The goals of this research were to show a beneficial use for acid whey and a soil amendment for sodic soils. These goals are in line with the Low Input Sustainable Agriculture (LISA) program of the USDA.

Materials and Methods

Greenhouse Experiment

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. Weight changes due to irrigation, evapotranspiration, and drainage in each lysimeter were monitored with a hydraulic weighing system (Robbins and Willardson 1980). Lysimeters contained 30 mm of 0.6-mm washed silica sand in the bottom for drainage. Freedom silt loam (fine–silty, mixed, mesic, Xerollic Calciorthids) surface soil (0–150 mm), which had not been previously irrigated or cultivated and had been stored in containers since 1987, was sieved through a 6-mm screen and placed on top of the sand to a depth of 850 mm. More of the same top soil was obtained from the field on 10 June 1991, and an additional 150 mm of soil was added to each lysimeter. The dry soil was 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 total pore volume of 33 L or an equivalent to 455 mm water depth. The 1991 top soil had an SAR of 13.3, an ESP of 10.2, and a cation exchange capacity (CEC) of 190 $mmol_c$ kg^{-1}; the saturation paste pH was 8.2 and the saturation paste extract EC was 1.1 dS m^{-1}. The 1987 soil had an SAR of 23.8 and an ESP of 22.6; the saturation paste pH was 8.1 and the saturation paste extract EC was 4.9 dS m^{-1}.

Cottage cheese whey was obtained from Dairy Gold, Inc. in Twin Falls, Idaho, where the milk is acidified using 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, an SAR of 3, pH of 3.3, and an EC of 7.7 dS m^{-1}. Treatments of 0, 25, 50, and 100 mm whey were applied on day 0 (11 June 1991), each randomly replicated three times. Table 1 shows total millimoles of cations added with each treatment of whey. Individual percentages of total cations added with each treatment were 25, 5, 20, and 50% for Ca, Mg, Na, and K on a molar basis.

Six days following whey treatment the top 150 mm of soil was removed and allowed

Table 1

Whey Treatment Depths, Volumes, and Cation Quantities Applied to Freedom Silt Loam in Lysimeters

Whey Depth (mm)	Whey Volume (L)	Cation Quantities (mmol)			
		Ca	Mg	Na	K
0	0	0	0	0	0
25	1.8	37	7	29	76
50	3.6	75	13	59	148
100	7.2	150	27	118	300

Note. Each lysimeter contained 0.72 m^3 of soil at an average bulk density of 1.4 Mg m^{-3}.

to dry. The crust material of whey solids was thoroughly mixed with the soil to simulate tillage. Each mixture was crushed through a 6-mm screen, returned to its respective lysimeter, and settled by vibration to the previous depth. All lysimeters then received 85 mm (6 L) of preplant irrigation water. The lysimeters were planted on day 7 with 15 barley (*Hordeum vulgare* L. cv. Ludd) seeds. The plants were later thinned to 11 plants per lysimeter. The barley was grown to maturity by irrigating using fresh water with 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 since the previous irrigation. Irrigation water SAR, EC, and pH were 1.5, 0.41 (dS m^{-1}), and 7.6, respectively. After harvest, additional water was added to each lysimeter to bring the accumulative leachate volume to approximately 0.5 pore volumes.

To promote crop growth, 10.0 g of urea were applied to each lysimeter 62 days after whey treatment. Because of an aphid infestation, 0.5 g of Temik granules were applied to each lysimeter 41 and 43 days after whey treatment.

Soil water samples were extracted from ceramic tubes (Robbins 1985) inserted into the soil through ports located at 0.25, 0.50, and 0.75 m below the soil surface and as drainage from the bottom of each lysimeter. Sample volume, EC, pH, and soluble Ca, Mg, Na, and K concentrations were measured. The EC was measured with a conductivity bridge and pH was determined using a pH meter and combination electrode. The Na and K concentrations were determined using flame photometry and Ca and Mg concentrations were measured using atomic absorption spectrophotometry.

At the end of the study, the soil profile was divided by depths at 0.00- to 0.15-, 0.15- to 0.30-, 0.30- to 0.60-, and 0.60- to 0.90-m sections. Saturated paste pH and saturated soil extract EC were measured. Exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} concentrations were determined by extraction of Ca^{2+} and Mg^{2+} with 1.0 M sodium acetate (adjusted to pH 8.2) and ammonium acetate (adjusted to pH 7.0) extraction of Na^{+} and K^{+} from soil samples (Robbins and Wiegand 1990).

Field Experiment

A nonreplicated basin experiment was conducted on a Declo loam (coarse-loamy, mixed, mesic, Xerollic Calciorthids) soil to determine whey application effects on infiltration rate and soil salinity changes. The soil had not previously been irrigated or cultivated and initially had an ESP of 20, CEC of 212 $mmol_c\ kg^{-1}$, saturation paste pH of 8.8, and saturation paste extract EC of 27 dS m^{-1}.

Basins were prepared by rototilling to a depth of 0.15 m. A 0.6-m-wide plastic liner was placed down to the tillage depth around the perimeter of each 2 × 2-m basin. A dike was erected to support the liner and to allow ponding of the whey and irrigation water. Whey was applied on day 0 (21 June) to the freshly tilled basins, which were randomly assigned treatments of 0, 25, 50, and 100 mm whey followed by additions of 100, 75, 50, and 0 mm well water to obtain a 100-mm application of liquid to each basin. Burlap sacks were laid on the soil surface prior to irrigation to minimize soil disturbance. One week later, each basin was hand tilled to a depth of 100 mm and leveled.

Infiltration rates were measured in each basin using three single-ring infiltrometers cut from 250-mm-inside-diameter pvc pipe to a length of 350 mm. These were driven to a depth of 100 mm on day 10 and to 180 mm on day 20 and left in place throughout the experiment. Basins received 150-mm irrigations on days 11, 20, 27, and 53. Irrigation

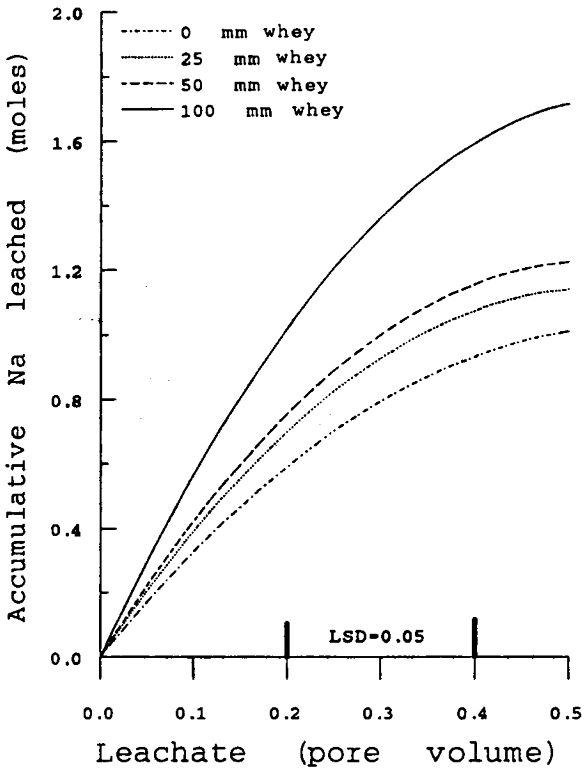

Figure 1. Accumulative amounts of lysimeter drainage water Na as a function of leachate volume and whey treatment from a Freedom silt loam. Dark vertical lines at 0.2 and 0.4 pore volumes show significance using LSD = 0.05.

Table 2

Whey Application Effects on Freedom Silt Loam SAR, ESP, Saturation Paste pH, and Saturation Extract EC in the Surface 0–150 mm After 0.5 Pore Volumes of Leachate

Whey Depth (mm)	SAR	ESP	pH	EC (dS m^{-1})
Initial soil	13.3	10.1	8.2	1.1
0	2.8 a	5.5 a	7.9 a	1.8 a
25	2.5 a	5.2 a	7.9 a	1.3 a
50	2.3 a	5.0 a	7.7 ab	1.2 a
100	2.2 a	4.8 a	7.4 b	1.9 a

Note. Numbers in the same column followed by the same letter are not significantly different at the $p = 0.05$ level ($n = 3$).

Table 3
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

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

water was simultaneously applied to the rings and the basin to prevent lateral flow from the infiltrometers. Well water was used for the first, second, and fourth infiltration tests and canal water was used for the third test.

Six days after the last infiltration test (day 59) triplicate soil samples from each basin were collected for chemical analysis at depths of 0–10, 10–50, 50–150, 150–250, 250–500, 500–750, and 750–1000 mm. Soil analysis was conducted using the same procedures used for the lysimeter soil.

Results and Discussion

Greenhouse Experiment

Sodium removal plotted as a function of leachate volume shows accumulative Na removal for the four whey treatments (Fig. 1). The slope of each curve at a given pore volume indicates the efficiency or instantaneous sodium removal rate. Efficiencies for the 25- and 50-mm treatments dropped to approximately that of the 0-mm treatment between 0.2 and 0.4 pore volumes, while the 100-mm treatment continued to be significantly more efficient beyond 0.4 pore volumes. Total sodium removed at 0.5 pore volumes was 1.0, 1.1, 1.2, and 1.7 mol for the 0-, 25-, 50-, and 100-mm treatments, respectively. Total amounts of sodium added by whey and irrigation water for the four treatments were 0.19, 0.19, 0.24, and 0.25 mol, respectively. Net sodium removed for each treatment was therefore 0.82, 0.95, 0.99, and 1.5 mol, respectively. Robbins (1986), using the same soil and lysimeter systems, showed similar Na-removal efficiencies for the nontreated soil, while the 100-mm whey treatment was similar to treating the soil with 5.0 kg chopped alfalfa or growing alfalfa, but not as effective as gypsum treatments or growing sorghum (*Sorghum bicolor*).

Soil analysis showed reclamation of the sodic soil taking place in the surface (0–150 mm) for all treatments (Table 2). Increasing the depth of whey treatments, tended to decrease soil SAR, ESP, and saturated paste pH. The lowering of the pH is evidence that further leaching would likely produce greater differences among treatments by solubilizing additional Ca, which would replace more Na. Saturation extract EC values did not show a trend, probably due to variations in water use by plants.

Barley grain yield for the 50-mm treatment was significantly greater than for the 0- and 25-mm treatments (Table 3). 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. Initial plant growth was slowed in the 100-mm treated lysimeters, probably by excess soluble salts and/or organic overloading.

Cumulative infiltration of the remaining 120 mm of a 150-mm irrigation was plotted against time by fitting a curve to the infiltration data (Fig. 2). Total infiltration times of the 25-, 50-, and 100-mm treatments were 320, 430, and 420% of the 0-mm treatment, respectively. The whey-treated soils were also slower infiltrating in most of the previous and subsequent lysimeter irrigations. Greenhouse temperatures (15–35 °C), the added biological substrate, and weekly irrigations provided a good environment for microbial activity. Increased microbial activity was evident on the surfaces of the whey-treated soils. Moist soils without adequate drying or resting periods between casein whey applications have shown increased biological activity and decreased infiltration rates in previous studies (McAuliffe et al. 1982).

Field Experiment

Field basin soil analyses showed reclamation taking place in all whey treatments for the 10- to 50- and 50- to 150-mm soil depths (Table 4). Values of saturation extract EC ranged from 0.9 to 2.1 dS m^{-1}, which were similar to values observed in the lysimeter

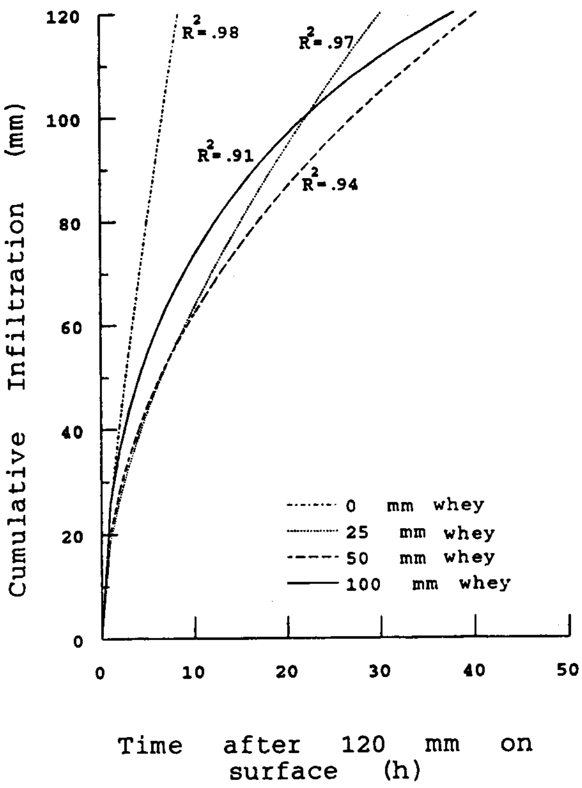

Figure 2. Cumulative infiltration of the final 120 mm of a 150-mm irrigation as a function of time and whey treatment in a Freedom silt loam.

Table 4

Whey Application Effects on Saturation Extract EC, Saturation Paste pH, SAR, and ESP for Two Depth Increments of a Declo Silt Loam

Whey Depth (mm)	EC (dS m^{-1})	pH	SAR	ESP
Initial soil	27 ± 14	8.8 ± 0.4	21 ± 11	20 ± 11
		10–50 mm soil depth		
0	1.3 ± 0.1[a]	8.5 ± 0.1	9.5 ± 1.2	11 ± 0.6
25	0.9 ± 0.1	8.1 ± 0.1	3.7 ± 0.6	7.9 ± 0.6
50	1.8 ± 0.4	8.0 ± 0.1	3.6 ± 0.4	5.9 ± 0.3
100	1.2 ± 0.2	7.7 ± 0.2	3.0 ± 0.3	5.4 ± 0.1
		50–150 mm soil depth		
0	1.4 ± 0.1	8.2 ± 0.1	9.3 ± 0.7	9.6 ± 1.4
25	1.0 ± 0.0	8.0 ± 0.1	3.5 ± 0.3	6.6 ± 0.6
50	2.1 ± 0.6	8.0 ± 0.2	6.0 ± 1.2	8.6 ± 2.5
100	1.2 ± 0.1	7.8 ± 0.1	3.0 ± 0.4	5.5 ± 0.6

[a] Average and standard deviation ($n = 3$ subsamples).

Table 5

Whey Application Effects on Saturation Extract Ca, Mg, Na, and K Concentrations for Two Depth Increments of a Declo Silt Loam

Whey Depth (mm)	Ca (mmol$_c$ L^{-1})	Mg (mmol$_c$ L^{-1})	Na (mmol$_c$ L^{-1})	K (mmol$_c$ L^{-1})
Initial soil	12 ± 6.8	2.5 ± 1.9	83 ± 34	18 ± 9.1
		10–50 mm soil depth		
0	1.0 ± 0.1[a]	0.3 ± 0.0	7.5 ± 0.2	4.6 ± 0.1
25	1.9 ± 0.1	0.5 ± 0.0	4.1 ± 0.3	4.3 ± 0.3
50	5.2 ± 0.8	1.6 ± 0.2	6.6 ± 0.8	5.7 ± 0.4
100	4.1 ± 0.2	1.0 ± 0.1	4.8 ± 0.2	4.7 ± 0.2
		50–150 mm soil depth		
0	1.0 ± 0.2	0.4 ± 0.1	7.6 ± 0.2	5.7 ± 0.1
25	2.0 ± 0.1	0.5 ± 0.0	4.0 ± 0.2	5.0 ± 0.2
50	4.3 ± 0.6	1.3 ± 0.1	10 ± 1.4	8.0 ± 0.7
100	2.9 ± 0.2	1.0 ± 0.2	4.2 ± 0.2	5.7 ± 0.2

[a] Average and standard deviation ($n = 3$ subsamples).

Table 6

Whey Application Effects on Exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} Changes for Two Depth Increments of a Declo Silt Loam

Whey Depth (mm)	Ca^{2+} ($mmol_c\ kg^{-1}$)	Mg^{2+} ($mmol_c\ kg^{-1}$)	Na^{+} ($mmol_c\ kg^{-1}$)	K^{+} ($mmol_c\ kg^{-1}$)
Initial soil	89 ± 22	5.6 ± 4.3	52 ± 29	122 ± 21
		10–50 mm soil depth		
0	120 ± 3.0[a]	17 ± 0.6	23 ± 1.4	112 ± 3.0
25	131 ± 2.3	18 ± 2.6	17 ± 1.2	111 ± 6.8
50	147 ± 4.4	20 ± 1.7	13 ± 0.6	105 ± 0.5
100	153 ± 8.0	20 ± 2.5	11 ± 0.1	99 ± 3.7
		50–150 mm soil depth		
0	121 ± 5.5	16 ± 2.1	20 ± 3.0	114 ± 7.4
25	124 ± 1.3	22 ± 0.9	14 ± 1.3	116 ± 4.0
50	140 ± 2.1	18 ± 1.0	18 ± 5.3	111 ± 3.0
100	145 ± 6.5	19 ± 1.2	12 ± 1.3	115 ± 14

[a] Average and standard deviation ($n = 3$ subsamples).

soil. Saturated paste pH was lowered in both field soil layers by whey applications. The SAR and ESP was lowered in both soil layers by all whey applications. Soluble Ca and Mg concentrations were increased by each whey treatment (Table 5). Soluble Na concentrations were decreased in all treatments in both upper depths. Soluble K concentrations were not noticeably affected by whey treatment. Exchangeable Ca and Mg concentrations in the soil for both layers were increased by all treatments and increased with whey application in the upper layer, while exchangeable Na concentrations decreased (Table 6). Exchangeable K concentrations were lowered in both the upper soil layers by whey application.

Throughout the first hour following whey application, the soil surface effervesced in random locations and soil particles and gases rose to the surface. The acid whey reacted with carbonate and bicarbonate salts in the soil (this reaction did not occur in the 0-mm whey treatment basin). During the infiltration tests, water in the three whey treatment basins was relatively sediment-free, while the nontreated basin water was murky due to soil particle dispersion. During the second and third infiltration tests the 100- and 50-mm basins had gas bubbles rising from the surface. Very little bubbling occurred in the 25- and 0-mm whey-treated basins.

Whey applications to field basins decreased infiltration time below that of the 0-mm treatment 11 and 53 days after whey application (Table 7). Infiltration times were greatest on day 27 when anaerobic conditions were noted in the upper 300 mm of soil. After a 4-week resting period, infiltration time for the 25-, 50-, and 100-mm treatments was 33, 31, and 26% of the 0-mm treatment, respectively. Infiltration improvement was likely a result of greater aggregate stability (Robbins and Lehrsch 1992), and reduced SAR and ESP from acid whey applications. Yahia et al. (1975) showed 93% sulfuric

Table 7
Whey Application Effects on the Infiltration Time (h) of 120 mm from a 150-mm Irrigation 11, 27, and 53 Days Following Whey Application in a Declo Silt Loam

Whey Depth (mm)	Average Time (h) to Infiltrate 120 mm at 11 Days[a]	27 Days	53 Days
0	7.1 ± 1.9[b]	63 ± 14	54 ± 16
25	3.9 ± 0.5	34 ± 4	18 ± 1
50	4.7 ± 0.6	79 ± 31	17 ± 13
100	3.5 ± 0.7	50 ± 30	14 ± 8

[a] Days since whey application. Data from irrigation on day 20 not shown.
[b] Average and standard deviation ($n = 3$ subsamples).

acid to be effective in increasing the rate of water penetration into sodic calcareous soils by increasing Ca^{2+} concentration and decreasing ESP and SAR.

Conclusions

Cottage cheese (acid) whey was shown to be a beneficial sodic soil amendment. Whey acidity, soluble Ca, Mg, and K, and readily decomposable organic matter should all contribute to soil reclamation. Increasing the depth of whey application lowers the soil SAR, ESP, and saturation paste pH. Results indicate that sodium removal is proportional to the amount of whey applied. These results would likely show greater differences if additional water had been run through the soil columns. Crop yield was improved by whey application where a single whey application rate was less than 100 mm. Increased microbial activity from whey organic matter may initially decrease infiltration rates. Given adequate resting periods, whey application followed by leaching appeared to improve infiltration.

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