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Effects of Acidic Cottage Cheese Whey on Chemical and Physical Properties of a Sodic Soil

C. W. ROBBINS
G. A. LEHRSCH

USDA-Agricultural Research Service
3793 N. 3600 E.
Kimberly, ID 83341, USA

Abstract *Sodic soil reclamation requires replacing exchangeable Na^+ with Ca^{2+} and leaching the excess Na^+ from the soil. Cottage cheese whey has an electrical conductivity (EC) of 6–10 dS m^{-1}, pH values of 4.2 or less, low sodium adsorption ratios (SAR), and contains 40–50 g kg^{-1} of readily decomposable organic matter. These whey characteristics should all be beneficial in reclaiming sodic soils. This study was conducted to determine the effects of cottage cheese whey on the chemical and physical properties of a sodic soil (SAR = 16.3, EC_e = 3.8, and pH 8.3). Cottage cheese whey was applied to 300-mm-deep sodic soil columns at 0-, 20-, 40-, and 80-mm rates followed by 80, 60, 40, and 0 mm of distilled water, respectively. The columns were then incubated at 10°C for 21 days, and then leached until 96 mm (0.60 pore volumes) of leachate was collected. All whey applications lowered the soil pH, SAR, and exchangeable sodium percentage (ESP) in both the upper and lower 150-mm-depth increments. Aggregate stability in the surface 150-mm-depth increment increased from 11% in the water-leached soil to 22% in the 80-mm whey-treated soil. The results of this study suggest that cottage cheese whey can be used as an effective sodic soil amendment.*

Keywords soil salinity, soil sodicity, soil reclamation, soil amendments, soil amelioration

Introduction

Cottage cheese whey generally has a pH of about 4.2 and Ca, Mg, Na, and K concentrations of about 13, 5, 27, and 57 mmol L^{-1}, respectively, for a total of about 102 mmol L^{-1}. It also contains about 36 g lactose and 9 g protein kg^{-1} (Summers and Okos 1982).

Sodic soil reclamation usually requires replacing exchangeable Na^+ with Ca^{2+}. The Ca^{2+} may be derived from dissolution of soil minerals, by addition of soluble Ca^{2+} amendments, or from Ca^{2+} dissolved in irrigation water. Sulfuric acid added to calcareous sodic soils has been used to dissolve lime and make Ca^{2+} available for replacing exchangeable Na^+ (Miyamoto et al. 1975). Carbonic acid produced by growing plant roots or decomposing organic matter has been shown to increase Ca solubility and thus speed sodic soil reclamation (Robbins 1986). Potassium additions to sodic soils also readily replace exchangeable Na^+ (Robbins and Carter 1983). Low infiltration and hydraulic conductivity rates are the predominant obstacles in reclaiming sodic soils. These low rates are due to soil particle dispersion caused by greater than normal exchangeable

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sodium percentages (ESP) and EC_e values less than 4.0 dS m^{-1}. Sodic soil reclamation requires increasing and maintaining infiltration and hydraulic conductivity rates sufficiently high to allow Na^+ leaching from the soil. Generally, the higher the soil solution soluble salt concentration, the greater is the hydraulic conductivity at a given ESP for a particular soil (Quirk and Schofield 1955).

Sweet whey, which comes from cheddar-type cheeses, has been shown to improve soil structure, provide plant nutrients, and lower the pH on two acid silt loam soils (Sharratt et al. 1959); however, no data were found for beneficial use of acid whey for sodic soil fertilization or reclamation. The application of cottage cheese whey to sodic and saline–sodic soils should have potential for reclaiming these soils. The acid nature of the whey should increase Ca solubility by decreasing soil solution pH. The readily decomposable lactose and proteins should increase the CO_2 level in the soil solution, and the H_2CO_3 formation would increase Ca solubility (Robbins 1985). The whey has a sodium adsorption ratio (SAR) of 6 or less at an electrical conductivity (EC) of 10–12 dS m^{-1}, based on the cation concentration. Potassium makes up over half of the cations in the whey. The combination of high electrolyte concentration and high K to Na concentration ratio would also be expected to increase the infiltration and Na^+ leaching rate in a sodic soil treated with acidic cottage cheese whey.

The purpose of this laboratory column study was to determine the effects of four acidic cottage cheese whey application rates followed by minimal leaching on chemical and physical properties and salt balance changes in noncropped sodic soil columns.

Materials and Methods

Surface soil (0.0–0.15 m) from a Freedom silt loam (fine-silty, mixed, mesic Xerollic Calciorthids) was used in this column study. The initial exchangeable sodium percentage (ESP) was 16, the cation exchange capacity (CEC) was 210 mmol charge kg^{-1} of soil, the saturation paste pH was 8.3, the saturation extract EC was 3.8 dS m^{-1}, and the saturation extract SAR was 16.3. This soil was selected because of its sodic nature (Robbins 1986).

The soil was passed through a 2.0-mm sieve and 1.000 kg of air dry soil was placed in each of twelve 82-mm-diameter columns. A medium-speed, ashless, 90-mm-diameter filter paper disk was placed above a 1-mm screen in the bottom of the columns prior to adding the soil. The ends of 0.2-m-long rods were fastened through the center of 75-mm-diameter stainless steel screen disks and the disks were placed on each soil surface with the rod standing upright. A second 1.000 kg of the same soil was then added to each column. Each column was then gently vibrated until each of the two soil increments was 150-mm deep. The resulting average bulk soil density was 1.26 Mg m^{-3}.

The whey used came from milk to which phosphoric acid (H_3PO_4) had been added at a rate equivalent to 3 g H_3PO_4 kg^{-1} of milk during cottage cheese manufacture. The whey contained 1.58 g P, 21 mmol Ca, 3.7 mmol Mg, 17 mmol Na, and 51 mmol K per kilogram of whey. The EC was 7.7 dS m^{-1}, the pH was 3.3, and the SAR was 3.3. This whey had higher Ca and lower Na, pH, and SAR values than those reported by Summers and Okos (1982).

The four treatments were 0, 20, 40, and 80 mm (0, 106, 213, and 425 mL) of cottage cheese whey followed by 80, 60, 40, and 0 mm of distilled water. The distilled water was added after the whey treatments had soaked into the soil columns. All treatments wet the soil columns to within 10-mm of the bottom and a few were wet to the bottom after 24 h. The total amounts of Ca, Mg, Na, K, and P added by each treatment

are shown in Table 1. The treatments were randomly replicated three times. The study was carried out in a constant temperature room at 10 °C.

Forty-eight hours after solution applications, the upper 150 mm of soil was removed by lifting the stainless steel screen, by the rod, from each column and the soil was allowed to partially air dry for 20 h at room temperature. The lower 150 mm of soil was left in the columns at 10 °C. Filter paper disks were placed on top of the remaining soil and replaced the stainless steel screens. The soil from the upper half of each column was sieved through a 2-mm screen, mixed (to simulate tillage), and returned to their respective columns and settled to the original volume.

Infiltration rates were immediately measured by adding 40 mm of distilled water to each column and the time required for the water surface depths to reach 30, 20, and 10 mm was determined. The columns were covered with watch glasses and incubated for 21 days at 10 °C. The infiltration rates were then measured a second time using the above procedure. The two 40-mm water applications did not add enough water to cause leaching.

After the incubation period and infiltration measurements, the columns were leached by adding 500 mL of distilled water and allowing them to drain overnight. The leachate volume was measured and sufficient additional water was added to produce 500 mL (equivalent to 96 mm depth or 0.60 pore volumes) of leachate. The final leachate for the twelve columns was 508 ± 8 mL. The total leachate was collected, combined from each column, and analyzed for Ca, Mg, Na, and K.

The soil was then removed from the columns as two samples. The top sample was from 0 to 150 mm and the bottom was from 150 to 300 mm. Each sample was divided lengthwise from top to bottom. One-half was used for saturation paste pH, saturation extract EC, and soluble cation analysis. One-fourth was used for orthophosphate and exchangeable cation analysis. The remaining one-fourth was used for aggregate stability determination.

Exchangeable plus soluble Ca^{2+} and Mg^{2+} were extracted with 1.0 molar sodium acetate (pH 8.2) and Na^{+} and K^{+} were extracted with 1.0 molar ammonium acetate (pH 7.0). Atomic absorption spectrophotometry was used for Ca and Mg measurements and flame photometry was used for Na and K measurements in both the acetate and saturation extracts. Exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} values were calculated as the difference between the saturation extract and acetate extract concentrations, adjusted to mmol kg^{-1} units. Exchangeable sodium percentages were calculated based on a CEC of 210 mmol kg^{-1} for the original soil. Orthophosphate was extracted with 0.5 M $NaHCO_3$

Table 1
Whey Application Depth and the Total Ca, Mg, Na, K, and P Added to Each 2.0-kg Soil Column by Each Treatment

Whey Depth (mm)	Ca (mmol)	Mg (mmol)	Na (mmol)	K (mmol)	P (g)
0	0	0	0	0	0
20	2.2	0.4	1.8	5.5	0.17
40	4.4	0.8	3.6	11.0	0.33
80	8.8	1.6	7.2	22.0	0.67

and determined by an ascorbic acid method (Watanabe and Olsen 1965). Aggregate stability was determined by sieving moist soil samples (14–21% moisture) to obtain 1- to 4-mm aggregates. Those aggregates were then vapor wetted to 0.30% moisture by weight prior to wet sieving (Kemper and Rosenau 1986, Lehrsch et al. 1991).

Results and Discussion

Leaching the soil with distilled water decreased the saturation extract EC in both depth increments and tended to increase the saturation paste pH (Table 2). That pH would be expected to increase in a sodic soil as a result of the electrolyte dilutions due to leaching (Robbins and Meyer 1990). Under the limited leaching regime used, the EC_e increased as the whey application rates increased. This was due to the high whey EC (7.7 dS m^{-1}). The pH generally decreased in both depth increments as the whey application rate increased. The pH decrease in the 20-mm treatment was due primarily to soluble carbonate (CO_3^{2-}) conversion to bicarbonate (HCO_3^-) by the phosphoric acid in the whey. Going from 20- to 40-mm whey did not change the saturation paste pH, because of HCO_3^- buffering. The 80-mm whey application lowered the pH to below 7 and this was due to neutralizing the remaining soluble bicarbonates (Robbins 1985).

Soil bicarbonate extractable P increased as the whey application rates increased in the upper soil depth increment, but showed little change in the lower depth increment. Even after the 80-mm whey application, P was still well within the range of a moderately P-fertilized soil. The 19-mg P kg^{-1} soil concentration in the soil is below the concentration of leaching concern from an environmental standpoint.

Table 2
Whey Application Depth Effects on the Saturation Paste pH, Saturation Extract EC, and Bicarbonate Extractable P for Two Depth Increments

Whey Depth (mm)	pH	EC (dS m^{-1})	P (mg kg^{-1})
	0- to 150-mm Soil Depth		
0	8.5 a	0.9 a	12 a
20	7.2 b	1.9 b	87 b
40	7.2 b	2.4 c	122 c
80	6.7 c	3.8 d	147 d
	150- to 400-mm Soil Depth		
0	8.5 a	1.4 a	13 a
20	7.4 b	2.9 b	11 a
40	7.3 b	3.7 c	12 a
80	6.8 c	4.2 d	19 b
Original soil	8.3	3.8	12

Note. Numbers in the same column for the same depth increment followed by the same letter are not significantly different at the $p = .05$ level.

Table 3
Whey Application Depth Effects on Saturation Extract Ca, Mg, Na, and K Concentrations and the Resulting SAR for Two Depth Increments

Whey Depth (mm)	Ca (mmol L^{-1})	Mg (mmol L^{-1})	Na (mmol L^{-1})	K (mmol L^{-1})	SAR
		0- to 150-mm Soil Depth			
0	0.4 a	0.2 a	8.3 a	1.8 a	10.7 a
20	3.5 b	2.5 b	8.4 a	5.4 b	3.4 b
40	4.7 c	3.5 b	7.8 b	6.5 b	2.7 c
80	8.4 d	6.6 c	7.4 c	12.2 c	1.9 d
		150- to 300-mm Soil Depth			
0	0.6 a	0.4 a	14.9 a	2.3 a	14.9 a
20	3.0 b	2.9 b	25.6 b	4.3 b	10.5 b
40	3.6 b	4.7 c	25.7 b	6.0 c	8.9 c
80	8.7 c	15.2 d	30.5 c	8.9 d	6.2 d
Original Soil	2.3	1.5	31.6	6.1	16.3

Note. Numbers in the same column for the same depth increment followed by the same letter are not significantly different at the $p = .05$ level.

All saturation extract cation concentrations and SAR values were decreased by leaching with distilled water (Table 3). All whey application rates increased the Ca^{2+} concentrations over the no-whey treatment. The differences between the 20- and 40-mm whey application rates were small compared to the other treatment differences. The whey treatment effects on Mg^{2+} concentrations were similar. These two ion concentrations were probably increased by the Ca and Mg added with the whey, dissolution of carbonates by the phosphoric acid, and by the increased CO_2 activity resulting from the whey organic matter decomposition (Robbins 1985). Under the limited leaching conditions of this study there was a net decrease of soluble Na^+ in the upper 150 mm for all treatments. There was a smaller decrease for the 0-, 20-, and 40-mm treatments in the lower 150-mm depth increment and essentially no change in the soluble Na^+ for the 80-mm whey treatment over the original soil. The fact that it did decrease is important when considering the amount of salt added to the soil by the whey treatments and the increases in the divalent cation concentrations. The 20-mm treatment lost K^+ and the 40-mm whey application rate did not change the soluble K^+ concentrations. Potassium concentrations were increased by the 80-mm application rate in both depth increments.

The saturation extract SAR decreased in the 0-mm whey treatment, compared to the original soil, because of dilution. All whey application rates produced additional SAR decreases. The decreases were greater in the upper depth increments than in the lower. Additional leaching would be expected to further decrease the SAR values in the whey-treated columns by dilution.

Exchangeable Ca^{2+}, Mg^{2+}, and K^+ were only very slightly decreased in the surface depth increment by the whey treatments (Table 4). Those three cations were decreased to a slightly greater degree in the lower depth increment. Exchangeable Na^+ was significantly decreased in the surface depth increment by each increase in whey application rate. The Na^{2+} decreased to a lesser extent in the lower depth increment by increases in

Table 4
Whey Application Depth Effects on Exchangeable Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, Total Exchangeable Cations (TEC), and the ESP for Two Soil Depth Increments

Whey Depth (mm)	mmol charge kg^{-1}					
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	TEC	ESP
			0- to 150-mm Soil Depth			
0	96 a	34 a	24 a	78 a	229 a	11.3 a
20	94 a	34 a	12 b	76 ab	215 b	5.5 b
40	94 a	33 a	10 c	76 ab	213 b	4.5 c
80	94 a	28 b	6 d	73 b	205 c	2.6 d
			150- to 300-mm Soil Depth			
0	96 a	38 a	28 a	82 a	232 a	13.3 a
20	82 b	38 a	19 b	77 ab	215 b	9.2 b
40	81 b	34 b	19 b	76 ab	210 bc	9.1 b
80	75 c	32 b	13 c	71 b	204 c	6.2 c
Original soil	89	37	27	79	232	14.9

Note. Numbers in the same column for the same depth increment followed by the same letter are not significantly different at the $p = .05$ level.

whey application rates. The total exchangeable cations (TEC) measured by the methods used decreased as the whey application rates increased.

The 80-mm whey treatment in the upper depth increment was the only treatment that increased aggregate stability over the no-whey check (Table 5). This was partially due to the fourfold decrease in exchangeable Na^{+}, and consequently ESP (Table 4). Decreasing the exchangeable Na^{+} would decrease the disruptive effects of the highly hydrated Na^{+} ion on soil structure. The soluble Ca^{2+}, Mg^{2+}, and K^{+} and EC (Table 3) increases would

Table 5
Whey Application Depth Effects on Aggregate Stability and Saturation Paste Water Contents

Whey Depth (mm)	Percent Stability		Water Content ($kg\ kg^{-1}$) Soil	
	0–150 mm	150–300 mm	0–150 mm	150–300 mm
0	11 a	8 a	0.35 a	0.35 a
20	12 a	9 a	0.39 b	0.38 b
40	18 ab	7 a	0.39 b	0.39 b
80	22 b	8 a	0.39 b	0.39 b
Original soil			0.36	

Note. Numbers in the same column followed by the same letter are not significantly different at the $p = .05$ level.

reduce the double-layer thickness next to the clay particles and would be expected to increase clay flocculation (Lehrsch et al. 1992). Drying and mixing the upper soil depth increment could have enhanced organic matter (whey decomposition products) positioning on soil particle surfaces and/or precipitate bonding agents at particle-to-particle contacts (Lehrsch et al. 1991). Additional leaching and wetting and drying cycles would be expected to enhance all of the above soil-stabilizing processes.

Saturation paste water contents in the whey-treated soils were greater than in the distilled water leached check, which also appears to be lower than the original soil. This change could have been caused by any one or more of the agents mentioned in the aggregate stability discussion.

The infiltration rates for the four treatments were not significantly different under these conditions, and thus are not reported. Whey application to soils has been shown to temporarily decrease infiltration rates, and then several months after 100- and 200-mm whey applications, both infiltration rates and aggregate stability again increased (Peterson et al. 1979, McAuliffe et al. 1982, Watson et al. 1977).

Conclusions

The results of this column study suggest that acidic cottage cheese whey can be used to reclaim saline–sodic and sodic soils. The whey has five characteristics that make this possible. It is a mild acid (pH 3.0–4.2), it has an EC greater than 7 dS m^{-1}, the SAR is less than 4, over half of the cations are K^+ (on a mM basis), and it contains an appreciable quantity of readily decomposable sugars and proteins. These factors all promote exchangeable Na^+ replacement and directly or indirectly promote infiltration rate increases over the long term. Caution should be exercised when choosing whey application rates, since high application rates have been shown to temporarily decrease infiltration rate in other studies. High salinity levels could also develop if whey application rates were too high in relation to irrigation water quality and leaching rates. Cottage cheese whey would not be expected to help reclaim saline (low sodium, high soluble salt) soils, but would likely compound the salinity problems. Further research is warranted under field and cropping conditions for the use of cottage cheese whey for reclaiming saline–sodic and sodic soils.

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