PHOSPHORUS STATUS OF CALCAREOUS AND SODIC SOILS TREATED WITH CHEESE WHEY

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ABSTRACT. *Acid cheese whey, made using phosphoric acid, contains up to 1200 mg total P* kg^{-1} *whey, and cultured cheese or sweet wheys contain up to 500 mg total P* kg^{-1} *whey. Much of the* 32×10^6 m^3 *of whey produced in the United States each year is applied to soil. Whey P mobility has not been documented for calcareous or sodic soils. This study was conducted to determine the ratio between ortho- and the more soluble organic P forms in freshly produced cheese whey, and to determine ortho- and organic P concentrations by depth within calcareous and sodic soils within one to two years of different whey rates and time of the year applications. Applications of up to 1050 kg P* ha^{-1} *in acid whey were applied to a sodic soil (in green house lysimeters) and up to 750 kg P* ha^{-1} *in sweet whey were applied to calcareous soils (field plots). Bicarbonate-extractable ortho-P did not move below 0.3 m in the sodic Freedom silt loam (fine-silty, mixed, mesic, Xerollic Calciorthid) soil by the end of one growing season. Neither bicarbonate-extractable nor saturation extract ortho- or organic P moved below 0.6 m in the calcareous Portneuf silt loam (coarse-silty, mixed, mesic, Durixerollic Calciorthid) soil after three growing seasons or below 0.3 m in the calcareous Nibley silty clay loam (fine, mixed, mesic Aquic Argiustolls) soil after two growing seasons. Even though the wheys contained up to 42% organic P, these soils retained the applied ortho- and organic P against leaching. The winter-applied whey-P did not move deeper into the soil than that applied during the growing season.* **Keywords.** *Soil, Phosphorous, Whey, Food processing waste, Organic fertilizer, Nutrient recycling, Waste recycling, Land application.*

Each kilogram (kg) of cheese manufacture produces 9 kg of whey by-product. Total whey production in the United States was about 32×10^6 m^3 in 1992 (calculated from National Agricultural Statistics Service, 1993 cheese production data). In Idaho, whey production increased from 0.5×10^6 m^3 in 1989 to 1.4×10^6 m^3 in 1993, (calculated from Idaho Agricultural Statistics Service 1995 data) and is expected to continue to increase.

Due to current and projected cheese and butter production growth in southern Idaho and northern Utah, and the need for economical and environmentally acceptable whey disposal methods, environmental and health control agencies must know the fate of whey P following whey application to calcareous soils in order to recommend acceptable whey disposal rates and methods.

Sweet whey, whey from cultured cheeses, can be ultrafiltered to remove the remaining proteins and the lactose can be removed by reverse osmosis. The resulting permeate also becomes a waste stream. Acid whey, whey from cheese made by coagulating milk with phosphoric acid (H_3PO_4), cannot be economically treated by reverse osmosis. Both whey types are also used directly as animal feed and land applied. Depending on the locality and economic factors, 20 to 100% of the fresh whey is land applied. The waste water from these other processes is also often land applied and contains about the same P content as fresh whey. Whey and permeate by-products are 92% water and contain 8% or less dissolved solids. Year around cheese production and the high hauling costs relative to plant nutrient value usually dictates land application near the whey source as a disposal method, in contrast to using whey as a fertilizer source. Cheese and whey processing plants also require emergency disposal sites when whey processing equipment is inoperative and for tainted milk disposal.

Properly applied whey and whey by-products can improve soil physical and chemical properties. Aggregate stability and infiltration rates can be increased when whey is applied to sodic (Lehrsch et al., 1994; Jones et al., 1993b) and acid soils (Kelling and Peterson, 1981; Watson et al., 1977).

Most P chemistry information for land-applied whey comes from acid to neutral soil studies. Wheys from various kinds of cheeses have been shown to increase available P levels in acid to near neutral soils in New Zealand (Radford et al. 1986), Wisconsin, and Michigan (Peterson et al., 1979). On these soils, crop P content and yield increased while ortho-P concentrations did not increase in the soil profile below 0.30 m. Organic P movement was not measured in those studies. The authors of this article did not find any data

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in the literature for non ortho-P concentrations in fresh whey, nor organic P concentrations or movement in soils.

Only limited information is available for ortho-P fate from whey applied to calcareous or sodic soils. Cottage cheese (acid) whey containing 1580 mg P L^{-1} applied to a sodic soil in laboratory columns at 0, 200, 400, and 800 m^3 whey ha^{-1}, incubated for 21 d, then leached, resulted in 12, 87, 122, and 147 mg bicarbonate extractable ortho-P kg^{-1} in the top 0.15 m of soil (Robbins and Lehrsch, 1992). Only the 800 m^3 ha^{-1} whey application increased the extractable ortho-P content (by 6 mg P kg^{-1}) in the 0.15-0.30 m depth.

Phosphorus from potato processing plant effluent (Robbins and Smith, 1977), beef feed lot manure (Meek et al., 1982), and turkey and beef manures (James et al., 1996) applied to calcareous soils moved deeper into the soil profile than would be expected if only ortho-P had been applied at the same rates. Hannapel et al. (1964) attributes greater than expected P movement in calcareous soils, treated organic wastes, to be due to organic P forms. They also showed that plant residue or sucrose additions to calcareous soils enhanced P movement over that of ortho-P additions only. Because whey is an organic material and P has been shown to move deeper into the soil under land application of other organic wastes than ortho-P, regulatory agencies are concerned about the fate of whey applied P.

A previous greenhouse lysimeter study of acid whey application to a sodic soil (Jones et al., 1993a,b) and three field studies of sweet whey application to calcareous soils (Lehrsch et al., 1994; Robbins et al., 1996) were designed to include measuring P movement below the root zone under different conditions and determine if these soils would retain ortho- and organic P against deep leaching. Those studies also included measuring physical and chemical changes caused by applying various kinds of whey at different rates and times of year.

The purposes of this article are to: (1) report the organic P fractions in whey from four cheese plants that make different cheese products; (2) report the changes in bicarbonate extractable ortho-P concentration changes with depth in a disturbed sodic soil treated with acid whey in greenhouse lysimeters; and (3) report the bicarbonate extractable and saturation paste extractable ortho- and organic P concentration changes with depth, in two calcareous soils treated with sweet whey at different times of the year.

MATERIALS AND METHODS

The acid whey used in Study One came from a cottage cheese plant and two samples were taken for chemical analysis (Jones et al., 1993a). The whey used in Studies Two and Three came from a plant that produces creamed and mozzarella cheeses (Robbins et al., 1996). Two samples were taken from each truck load for a total of 16 samples over a two-year study period. The Study Four whey came from a plant that makes Swiss and mozzarella cheeses and two samples were taken from each load for a total of 20 samples over the 16-month study period. An additional four whey samples from a cheddar cheese plant and four whey samples from a processed cheese plant were collected over a two-year period for comparison to the wheys used in the above studies. Only total P was measured on the acid cottage cheese whey used in Study One (table 1). The rest of the samples were analyzed for total and ortho-P. Total P in all whey samples was oxidized to ortho-P by drying 20 g samples at 60°C for two days and ashing the dried whey at 500°C until white. The ash was dissolved by boiling for 10 min in 10 mL of 1.0 molar nitric acid. Ortho-P was then determined by an ascorbic acid method (Watanabe and Olsen, 1965). Ortho-P was measured directly on the fresh whey used in Studies Two, Three, and Four plus the two additional cheese plant whey samples by the same ascorbic acid method. The difference between the total and ortho-P was assumed to be organic P.

Study One treatments were applied 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 dS m^{-1}] Freedom silt loam (fine-silty, mixed, Xerollic Calciorthid). The soil was in 1.0 m deep × 0.30 m diameter greenhouse weighing lysimeters (Robbins and Willardson, 1980). This study was conducted to measure reclamation in a saline-sodic soil by acid cottage cheese whey (Jones et al., 1993b) and to measure P leaching, reported here for the first time. The initial bicarbonate extractable ortho-P concentration in the thoroughly mixed soil was 5 mg P kg^{-1} soil. A completely randomized design with four treatments replicated three times was used.

The whey used in this study was the result of adding an equivalent of 3 g of phosphoric acid (H_3PO_4) kg^{-1} milk for acidification during cottage cheese coagulation (table 1). One time treatments of 0, 250, 500, and 1000 m^3 ha^{-1} acid cottage cheese whey were applied (Jones et al., 1993b), resulting in 0, 263, 525, and 1050 kg P ha^{-1} additions. After the whey infiltrated into the soil, 100, 75, 50, and 0 mm H_2O applications were applied to the respective treatments to bring the soils to the same moisture content. Seven days after irrigation the soil was tilled to mix the whey into the upper 0.10 m of soil. Barley (*Hordeum vulgare* L. cv. Ludd) was then planted and irrigated until it matured. The lysimeter soils were irrigated at 1.25 times evapotranspiration 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 to 0.15, 0.15 to 0.30, 0.30 to 0.60, and 0.60 to 0.90 m depth increments and air dried. The 0.5-M bicarbonate extractable ortho-P concentration in each depth increment was determined using an ascorbic acid method (Watanabe and Olsen, 1965) (table 2). Organic P was not measured in this study.

Table 1. Chemical composition of wheys used in this study

	Total P	Organic P	Ca	Mg	Na	K		pH	EC
	mg kg^{-1} (mmol l^{-1})						SAR		dSm^{-1}
Study One	1050	-	840	97	368	1642	3.0	3.3	7.7
(acid whey)	(34)	-	(21)	(4)	(16)	(42)			
Studies Two	470	170	680	97	480	1200	4.6	4.0	7.1
and Three	(15)	(5)	(17)	(4)	(21)	(30)			
Study Four	310	130	440	87	345	1020	4.1	4.0	7.0
	(10)	(4)	(11)	(3.6)	(15)	(26)			

Table 2. Bicarbonate extractable ortho-P concentrations, by depth, in a sodic Freedom silt loam soil treated with acid cottage cheese whey in greenhouse lysimeters

Total P added (kg P ha^{-1})	Depth 0 - m 0.15 m	0.15 - 0.30 m	0.30 - 0.60 m	0.60 - 0.90 m
	(mg P kg^{-1})			
0	4.9 a*	4.8 a	5.0 a	6.2 a
263	14. b	6.8 a	4.1 a	5.2 a
525	29. c	10. ab	5.5 a	6.0 a
1,050	30. c	12. b	6.3 a	6.8 a

* Numbers in a column followed by the same letters are not different at the P ≤0.05 level (Duncan's Multiple Range Test).

Studies Two and Three were conducted to determine P movement through and to measure chemical changes (Robbins et al., 1996) in a calcareous soil for winter and growing season whey applications, respectively. The whey used in these studies was a mixture of creamed cheese whey that contained added H_3PO_4 and mozzarella whey that contained P only from the milk (table 1). The treatments consisted of annual total applications of 0, 200, 400, and 800 m^3 whey ha^{-1} in 200 m^3 ha^{-1} increments on the dates shown in table 3. The whey was applied over a two year period. Study Two applications were applied during the winter seasons and Study Three applications were applied during the winter wheat (*Triticum aestivum* L. cv. Malcolm) growing seasons. The annual total-P applications were 0, 94, 188, and 376 kg P ha^{-1}. Each of the four treatments in each study were replicated three times in randomized complete block designs on adjacent field sites. The plots were on a calcareous Portneuf silt loam (coarse-silty, mixed, mesic, Durixerollic Calciorthid).

Winter wheat was planted on 15 September 1992 and again on 20 September 1993. After planting, the plots (12 × 15 m) were furrowed (0.1 m deep on 0.75 m centers) for the whey application and then dikes were built around each plot to contain the whey, irrigation water, and precipitation. The plots were sprinkler irrigated twice in 1993 and three times in 1994 as needed for optimum wheat growth. On 10 April 1995, the plots were lightly cultivated, planted to alfalfa (*Medicago sativa* L.) and furrowed for surface irrigation. No additional treatments were applied. The alfalfa was harvested on 27 June, 3 August, and 26 September 1995. The alfalfa was furrow irrigated three times, once before each cutting.

On 2 September 1994 and again on 28 September 1995, four, 75-mm-diameter soil samples were taken from each plot at 0 to 0.3, 0.3 to 0.6 and 0.6 to 0.9-m depth increments, and the four samples from each depth were mixed and a 5-kg subsample was air-dried and ground for chemical analysis. Ortho- (Watanabe and Olsen, 1965) and total P (Greenberg et al., 1992) concentrations were measured on bicarbonate extracts and saturation paste extracts (tables 4, 5, 6, and 7).

Study Four was conducted to determine P movement through and measure chemical changes (Robbins et al., 1996) in a calcareous soil during year around whey applications to a calcareous soil. The whey was a mixture of Swiss and mozzarella cheese whey (table 1). The treatments consisted of applying whey in 200 m^3 ha^{-1} increments over a 15-month period on the dates shown in table 8. The total whey applications for the four treatments were 0, 600, 1200, and 2200 m^3 ha^{-1} for total P applications of 0, 183, 366, and 671 kg ha^{-1}. The plots (6 × 6 m) were established in an existing alfalfa field north of Logan Utah on a highly calcareous Nibley silty clay loam (fine, mixed, mesic Aquic Argiustolls). The four treatments were replicated three times in a completely randomized design. The plots were flood irrigated as needed when the entire field was irrigated.

On 7 June 1994, the plot soils were sampled from 0 to 0.30 and 0.30 to 0.60 m. Four soil samples were taken from each depth in each plot, mixed and then 5-kg soil subsamples were air dried and ground prior to chemical

Table 3. Total P applications were applied to Studies Two and Three on dates shown (whey was applied in 200-m^3 whey ha^{-1} increments)

	Year 1							
	Study Two				Study Three			
	8 Dec 1992	19 Jan 1993	2 Mar 1993	20 Apr 1993	18 May 1993	8 Jun 1993	28 Jun 1993	21 Jul 1993
P Added y^{-1}	(kg total P ha^{-1})				(kg total P ha^{-1})			
0	0	0	0	0	0	0	0	0
94	0	0	94	0	0	94	0	0
188	0	94	0	94	94	0	94	0
376	94	94	94	94	94	94	94	94
	m							
Frost*	0.32	0.36	0.50	0.00				
	Year 2							
	30 Nov 1993	28 Dec 1993	27 Jan 1994	22 Feb 1994	10 May 1994	16 May 1994	12 Jun 1994	1 Jul 1994
	(kg total P ha^{-1})				(kg total P ha^{-1})			
0	0	0	0	0	0	0	0	0
92	0	94	0	0	0	94	0	0
188	94	0	94	0	94	0	94	0
376	94	94	94	94	94	94	94	94
	m							
Frost*	0.23	0.25	0.15	0.30				

* Frost depth in methylene blue frost tubes.

Table 4. Study Two (winter whey application) ortho- and organic-P concentrations in bicarbonate and saturation paste extracts by depths and treatments for samples taken 2 Sept 1994

	Bicarbonate Extract					
Total P Added (kg P ha^{-1})	Ortho P			Organic P		
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P kg^{-1} Soil)			(mg P kg^{-1} Soil)		
0	4.1 a*	1.9 a	1.0 a	2.0 a	0.7 a	1.7 a
188	9.1 b	3.1 ab	1.0 a	2.1 a	0.6 a	1.3 a
376	27. c	3.6 bc	0.9 a	3.8 b	0.8 a	1.3 a
752	53. d	6.1 c	1.4 a	5.5 b	1.0 a	1.3 a
	Saturation Paste Extract					
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P l^{-1} Extract)			(mg P l^{-1} Extract)		
0	0.10 a	0.02 a	0.03	0.14 a	0.04 a	0.03 a
188	0.13 a	0.02 a	0.04 a	0.18 a	0.04 a	0.02 a
376	0.68 b	0.01 a	0.02 a	0.36 ab	0.05 a	0.03 a
752	1.8 c	0.01 a	0.03 a	0.85 b	0.11 b	0.02 a

* Numbers in a column of four values followed by the same letter are not different at the P ≤0.05 level (Duncan's Multiple Range Test).

Table 5. Study Two (winter whey application) ortho- and organic-P concentrations in bicarbonate and saturation paste extracts by depths and treatments for samples taken 28 Sept 1995

	Bicarbonate Extract					
Total P Added (kg P ha^{-1})	Ortho P			Organic P		
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P kg^{-1} Soil)			(mg P kg^{-1} Soil)		
0	4.4 a*	2.5 a	1.1 a	2.3 a	0.8 a	0.8 a
188	13. b	2.8 a	1.1 a	2.2 a	0.7 a	0.9 a
376	29. c	3.1 a	1.0 a	3.2 ab	1.1 a	1.1 a
752	53. d	7.1 b	1.5 a	6.4 b	2.0 a	1.4 a
	Saturation Paste Extract					
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P l^{-1} Extract)			(mg P l^{-1} Extract)		
0	0.05 a	0.02 a	0.02 a	0.15 a	0.04 a	0.04 a
188	0.06 a	0.02 a	0.02 a	0.22 a	0.06 ab	0.04 a
376	0.18 a	0.02 a	0.02 a	0.36 ab	0.07 b	0.04 a
752	0.53 b	0.02 a	0.02 a	0.58 b	0.12 c	0.04 a

* Numbers in a column of four values followed by the same letter are not different at the P ≤0.05 level (Duncan's Multiple Range Test).

Table 6. Study Three (growing season whey application) ortho- and organic-P concentrations in bicarbonate and saturation paste extracts by depths and treatments for samples taken 2 Sept 1994

	Bicarbonate Extract					
Total P Added (kg P ha^{-1})	Ortho P			Organic P		
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P kg^{-1} Soil)			(mg P kg^{-1} Soil)		
0	4.7 a*	4.5 a	1.0 a	1.6 a	1.6 a	0.9 a
188	18. b	4.1 a	1.1 a	1.6 a	1.2 a	1.4 a
376	42. c	11. b	1.1 a	7.6 b	1.2 a	1.1 a
752	69. d	18. b	1.9 a	13. c	1.8 a	1.2 a
	Saturation Paste Extract					
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P l^{-1} Extract)			(mg P l^{-1} Extract)		
0	0.08 a	0.06 a	0.04 a	0.19 a	0.10 a	0.02 a
188	0.62 b	0.05 a	0.02 a	0.31 ab	0.07 a	0.03 a
376	2.25 c	0.05 a	0.02 a	0.39 bc	0.08 a	0.03 a
752	2.63 c	0.13 a	0.05 a	0.52 c	0.09 a	0.02 a

* Numbers in a column of four values followed by the same letter are not different at the P ≤0.05 level (Duncan's Multiple Range Test).

Table 7. Study Three (growing season whey application) ortho- and organic-P concentrations in bicarbonate and saturation paste extracts by depths and treatments for samples taken 28 Sept 1995

	Bicarbonate Extract					
Total P Added (kg P ha^{-1})	Ortho P			Organic P		
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P kg^{-1} Soil)			(mg P kg^{-1} Soil)		
0	6.3 a*	4.2 a	1.1 a	2.5 a	1.7 a	0.9 a
188	16. b	3.8 a	1.3 a	3.0 a	1.5 a	1.0 a
376	40. c	5.2 ab	1.4 a	3.7 ab	1.8 a	1.0 a
752	61. d	9.9 b	2.2 a	6.8 b	1.9 a	0.9 a
	Saturation Paste Extract					
	Depth			Depth		
	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m	0.0 - 0.3 m	0.3 - 0.6 m	0.6 - 0.9 m
	(mg P l^{-1} Extract)			(mg P l^{-1} Extract)		
0	0.06 a	0.02 a	0.02 a	0.19 a	0.04 a	0.03 a
188	0.16 b	0.02 a	0.02 a	0.24 a	0.05 a	0.02 a
376	0.80 c	0.02 a	0.02 a	0.38 a	0.07 a	0.02 a
752	1.2 c	0.03 a	0.02 a	0.38 a	0.09 a	0.03 a

* Numbers in a column of four values followed by the same letter are not different at the P ≤0.05 level (Duncan's Multiple Range Test).

analysis. Ortho- and total P concentrations were measured in bicarbonate and saturation paste extracts (table 9).

RESULTS

The whey used in Studies Two and Three plus the samples collected from a cheddar cheese plant and a processed cheese plant were found to contain 63 ±2% ortho- and 37 ±2% organic P. The whey used in Study Four contained 58 ±2% ortho-P and 42 ±2% organic P.

Study One 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} applications in the 0.15- to 0.30-m depth increment (table 2). Below 0.30 m, the

Table 8. Total P applications were applied to Study Four on dates shown (whey was applied in 200 m^3 ha^{-1} increments)

Treatment	14 Jan 1993	18 Feb 1993	29 Mar 1993	7 Jul 1993	16 Aug 1993	30 Sep 1993	18 Nov 1993	27 Jan 1994	25 Feb 1994	25 Mar 1994	Total P Added
	kg P ha^{-1}					kg P ha^{-1}					
1	0	0	0	0	0	0	0	0	0	0	0
2	61	0	0	61	0	0	0	61	0	0	183
3	61	61	0	61	0	61	0	61	0	61	366
4	61	122	61	61	61	61	61	61	61	61	671

Table 9. Study Four (year around whey application) ortho- and organic-P concentrations in bicarbonate and saturation paste extracts by depths and treatments

Total P Added (kg P ha^{-1})	Bicarbonate Extract			
	Ortho P		Organic P	
	Depth		Depth	
	0.0 - 0.3 m	0.3 - 0.6 m	0.0 - 0.3 m	0.3 - 0.6 m
	(mg P kg^{-1} Soil)		(mg P kg^{-1} Soil)	
0	14. a*	12. a	8.5 a	8.1 a
184	22. b	7. a	8.3 a	6.2 a
368	26. b	10. a	8.2 a	5.7 a
675	48. c	15. a	7.2 a	3.5 a
	Saturation Paste Extract			
	Depth		Depth	
	0.0 - 0.3 m	0.3 - 0.6 m	0.0 - 0.3 m	0.3 - 0.6 m
	(mg P l^{-1} Extract)		(mg P l^{-1} Extract)	
0	0.15 a	0.11 a	0.30 a	0.36 a
184	0.52 b	0.10 a	0.73 a	0.18 a
368	0.61 b	0.20 a	0.30 a	0.24 a
675	0.77 b	0.35 b	0.54 a	0.35 a

* Numbers in a column of four values followed by the same letter are not different at the P ≤0.05 level (Duncan's Multiple Range Test).

bicarbonate extractable ortho-P concentrations were not significantly different.

Study Two bicarbonate extractable ortho-P concentrations increased in the surface 0.3 m for all whey additions and in the 0.3- to 0.6-m increments by the 376- and 752-kg P ha^{-1} treatments in the 1994 sampling (table 4). Bicarbonate extractable organic P increased only in the surface 0.3 m following the 376- and 752-kg P ha^{-1} treatments. Saturation paste extractable ortho- and organic P was increased in the surface 0.3 m by the 376- and 752-kg P ha^{-1} treatments, and the organic P was increased in the second depth by the 752-kg P ha^{-1} treatment. There were essentially no P concentration changes between the 1994 to the 1995 bicarbonate extractable P values (tables 4 and 5). The 1995 saturation extract ortho-P concentrations in the surface 0.3 m of the 376- and 752-kg P ha^{-1} plots decreased to less than one-third of the 1994 values. The rest of the saturation extract P values were unchanged.

Study Three 1994 bicarbonate extractable ortho-P concentrations were increased by all P application rates in the surface 0.3 m and by the 376- and 752-kg P ha^{-1} applications in the 0.3- to 0.6-m depths (table 6). Bicarbonate extractable organic P was increased in the surface depth increment only by the 376- and 752-kg P ha^{-1} applications. The saturation extract ortho-P concentrations were increased by all application rates and the organic P concentrations were increased by the 376- and 752-kg P ha^{-1} treatments in the surface 0.3 m. The 1995 bicarbonate extractable P values from plots and depths that were significantly increased in 1994 were slightly lower than the 1994 values (table 7). However, the outcome was essentially the same in that only the surface 0.3 m of the treated plots and the 0.3- to 0.6-m depths of the plots receiving the highest application rate had significantly higher ortho-P concentrations than the control plots, and only the surface 0.3-m organic P was increased by the highest P loading rate. The 1995 0.3-m saturation extract ortho-P concentrations for all three whey additions were less than half of the 1994 concentrations. The rest of the 1995 saturation extract ortho- and all of the organic P concentrations were not different from the untreated plot values.

Comparing table 4 data with that in table 6, and table 5 data with that in table 7 suggests that whey P applied to cold and frozen soils did not move any deeper than that applied during the winter wheat growing season.

Study Four bicarbonate extractable ortho-P concentrations in the Nibley soil were increased in the 0.0-0.3 m depths by all three whey application rates, but were not significantly affected in the 0.3-0.6 m depths (table 9). Saturation paste extract ortho-P concentrations were also increased by all treatments in the 0.0-0.3 m depths, but only by the highest whey application rate in the 0.3-0.6 m depth. Organic-P concentrations, due to whey applications, did not increase in the bicarbonate or saturation paste extracts in the 0.0-0.3 m nor 0.3-0.6 m depth increments.

DISCUSSION

A single 1000 m^3 ha^{-1} whey application adding 1050 kg P ha^{-1} did not significantly increase bicarbonate extractable ortho-P below 0.3 m in a disturbed sodic Freedom soil profile. Each liter of whey contains about 1050 mg (34 mmoles) of total P and 840 mg (21 mmoles) Ca l^{-1}. This soil contained 3400 to 3800 mg (85 to 95 mmoles) exchangeable Ca kg^{-1} and initially contained 20 mg (0.5 mmoles) Ca l^{-1} in the saturation paste extract. The whey lowered the surface soil pH from 8.2 to 7.4 (Jones et al., 1993b). The added Ca plus the lowered pH (Robbins, 1985) increased the exchangeable Ca to 5600 mg (140 mmoles) Ca kg^{-1} soil and increased the saturation paste extract Ca concentration to over 160 mg (4 mmoles) l^{-1} in the surface 0.15 m by the two highest whey treatments. The combination of these two Ca sources provided sufficient Ca for ortho-P precipitation (Lewis and Raca, 1969). The added ortho-P and any organic P that was converted to ortho-P, that was not measured as bicarbonate extractable ortho-P, was likely adsorbed to the soil or precipitated as one of several possible calcium phosphates (Griffen and Jurinak, 1973). Even though this soil retained the bicarbonate extractable ortho-P from a very high single P application rate, the question of soluble organic whey P movement or mineralization was not addressed.

The cultured cheese wheys tested contained up to 42% non-ortho-P which is assumed to be in organic form(s). Because P has been shown to move deep into soil profiles when applied in organic forms (James et al., 1996; Meek et al., 1982; Robbins and Smith, 1997), the possibility of high organic P concentrations in land applied whey has caused concern. The net P movement will depend on the degree and rate it is adsorbed or mineralized to ortho-P.

Neither water soluble nor bicarbonate-extractable ortho- or organic P increases were detected below 0.6 m in the Portneuf soils by the end of three growing seasons for application rates up to 752 kg P ha^{-1} over two years. Organic P movement from whey applied to cold or frozen soils is also a concern of the regulatory agencies. These results suggest that the winter whey-applied ortho- and organic P is no more likely to move deeper into the profile than P applied during the growing season. There was no indication of either P form moving below 0.3 m in the highly calcareous Nibley soil when up to 675 kg P ha^{-1} was applied over an eighteen month period. The whey Ca plus soil Ca concentrations are sufficient in this soil for ortho-P precipitation (Robbins et al., 1996)

These studies do not suggest that these P application rates should be applied for extended periods. Even though whey contains up to 42% organic P, these soils have the capacity to retain these high P additions against leaching under these conditions. It also appears that the organic P in the whey is only slightly more mobile than the ortho-P, or that it is rapidly converted to ortho-P in the soil. Whey organic P does not appear to be as mobile as manure or potato waste organic P.

It should be noted that these treatments were not applied to wet soils, nor were the soils leached immediately after whey application. If these treatments were applied to wet soils or if heavy irrigation or rain were to follow the whey applications, it is possible that the organic P might have moved deeper into the soils.

Phosphorus loading at these rates will likely not produce ground water contamination in the short term. If these rates, which are excessive for plant needs are to continue indefinitely, deep profile monitoring should be included as part of the management practice, since soils can be overloaded with ortho-P under extreme loading rates.

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REFERENCES

Greenberg, A. E., L. S. Clesceri and A. D. Eaton, eds. 1992. Standard Methods for the Examination of Water and Waste Water, 18th Ed., 4-112. Washington, D.C.: Am. Public Health Assoc.

Griffen, R. A. and J. J. Jurinak. 1973. The interaction of phosphate with calcite. *Soil Sci. Soc. Am. Proc.* 37(6):847-850.

Hannapel, R. J., W. H. Fuller, S. Bosma and J. S. Bullock. 1964. Phosphorus movement in a calcareous soil: I. Predominance of organic forms of phosphorus in phosphorus movement. *Soil Sci.* 97(5):350-357.

Idaho Agricultural Statistics Service. 1995. *Idaho Agricultural Statistics.* Boise, Idaho: Idaho Dept. of Agriculture and USDA.

James, D. W., J. Kotuby-Amacher, G. L. Anderson and D. A. Huber. 1996. Phosphorus mobility in calcareous soils under heavy manuring. *J. Environ. Qual.* 25(4):770-775.

Jones, S. B., C. L. Hansen and C. W. Robbins. 1993a. Chemical oxygen demand fate from cottage cheese (acid) whey applied to a sodic soil. *Arid Soil Res. Rehab.* 7(1):71-78.

Jones, S. B., C. W. Robbins and C. L. Hansen. 1993b. Sodic soil reclamation using cottage cheese (acid) whey. *Arid Soil Res. Rehab.* 7(1):51-61.

Kelling, K. A. and A. E. Peterson. 1981. Using whey on agricultural land — A disposal alternative. Serial No. A3098. Madison, Wis.: Coop. Ext. Program, University of Wisconsin.

Lehrsch, G. A., C. W. Robbins and C. L. Hansen. 1994. Cottage cheese (acid) whey effects on sodic soil aggregate stability. *Arid Soil Res. Rehab.* 8(1):19-31.

Lewis, E. T. and G. T. Raca. 1969. Phosphorus movement in some calcareous and non calcareous Manitoba soils. *Can. J. Soil Sci.* 49(3):305-312.

Meek, B., L. Graham and T. Donovan. 1982. Long-term effects of manure on soil nitrogen, phosphorus, sodium, organic matter, and water infiltration rate. *Soil Sci. Soc. Am. J.* 46(5):1014-1019.

National Agricultural Statistics Service. 1993. *Agricultural Statistics.* Washington, D.C.: USDA.

Peterson, A. E., W. G. Walker and K. S. Watson. 1979. Effect of whey applications on chemical properties of soils and crops. *J. Agric. Food Chem.* 27(4):654-658.

Radford, J. B., D. B. Galpin and M. F. Parkin. 1986. Utilization of whey as a fertilizer replacement for dairy pasture. *New Zealand J. Dairy Sci.* 21(1):65-72.

Robbins, C. W. 1985. The $CaCO_3$-CO_2-H_2O system in soils. *J. Agron. Educ.* 14(1):3-7.

Robbins, C. W., C. L. Hansen, M. F. Roginske and D. L. Sorensen. 1996. Bicarbonate extractable K and Soluble Ca, Mg, Na, and K status of two calcareous soils treated with whey. *J. Environ. Qual.* 25(4):791-795.

Robbins, C. W. and G. L. Lehrsch. 1992. Cottage cheese whey effects on sodic soils. *Arid Soil Res. Rehab.* 6(2):127-134.

Robbins, C. W. and J. H. Smith. 1977. Phosphorus movement in calcareous soils irrigated with waste water from potato processing plants. *J. Environ. Qual.* 6(2):222-225.

Robbins, C. W. and L. S. Willardson. 1980. An instrumented lysimeter system for monitoring salt and water movement. *Transactions of the ASAE* 23(1):109-111.

Watanabe, F. S. and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soils. *Soil Sci. Soc. Am. Proc.* 29(6):677-678.

Watson, K. S., A. E. Peterson and R. D. Powell. 1977. Benefits of spreading whey on agricultural land. *J. Water Pollut. Control Fed.* 49(1):24-34.