Typical food applications for whey include: bread and other baked goods, infant and dietetic foods, ice cream and other frozen desserts, cereals, soups, sauces, toppings and dressings, snack foods, confections, and beverages, to name a few. In addition, whey and modified whey have been utilized as food ingredients in P. L. 480 programs, where they play an important role in feeding malnourished peoples of developing countries. During the symposium, particular animal feed and industrial applications for whey will be discussed.

Table I summarizes U.S. fluid whey and whey solids production and the quantity of these whey solids currently estimated to be processed. Obviously, while considerable quantities of the whey solids presently available are being further processed and utilized, additional quantities are available for processing and use. During the course of this symposium, information will be given about potential processes that soon may lead to the processing/utilization of all available whey solids.

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Effect of Whey Applications on Chemical Properties of Soils and Crops

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Investigations were conducted to determine the effects of cheese whey application on agricultural cropland. One season whey additions of 4, 8, 16, and 32 in. to soil in Wisconsin showed significant yield and quality increases in corn grown over a 4-year period. In Michigan, annual applications of 3.3 in. of whey over 18-year period increased the surface soil phosphorus and potassium concentrations to abundant levels. Deeper soil profile samples showed limited downward movement of these nutrients. In Idaho, whey in irrigation waters had no significant measured impact on the quality of the ground water underlying the site. Unless excessive applications were made, no effect of nutrient buildup that would adversely influence soil productivity was noted. We conclude that land application of whey, either from truck spreading or through irrigation water, can be practiced with beneficial effects for the land and its productivity.

Public concern for pollution control has prompted the dairy industry to give greater attention to the water-pollution potential of disposable whey. The processing of whey into food and feed supplements is hampered today by increasing energy costs and is economical only at large cheese plants. The small, scattered cheese plants cannot individually or jointly afford the necessary condensing and drying facilities and therefore must dispose of the whey in some other manner.

Kraft, Inc., and similar industries, by necessity, are using the land to dispose of whey. In 1972, the Kraft firm began a project at the University of Wisconsin—Madison to evaluate this disposal method.

The results from the University of Wisconsin—Madison study were reported by Watson et al. (1977). Results showed that land spreading of whey can be practiced to the mutual benefits of the landowners and the cheese plant operators by increasing the fertility of land while providing a satisfactory method of whey disposal.

Test plots in the Wisconsin study were heavily dosed with whey. We report observable changes in the composition of the soil and the corn grown on these plots. In addition, land used for whey disposal by Kraft plants in Rupert, Idaho, and Clare, Michigan, are examined briefly as are crops grown on this land.

The plant food contained in 1 acre-inch of whey (27 300 gal, or 226 000 lb), as indicated in Morrison (1967), is about 320 lb of nitrogen, 100 lb of phosphorus, and 400 lb of potassium.

EARLIER WORK

The earliest known work was that of Berry (1923) in Scotland, where the only apparent effect of whey application on land was greater growth of the coarser grasses. Berry concluded that whey was beneficial to the soil but that high hauling costs would usually make it unprofitable. Cain (1956) studied the nutritive value of whey applied to plants grown in the greenhouse on a Miami silt loam soil. He found responses from whey application to both oats and blue-grass sod, although he felt that little nitrogen in the whey is released to plants during the early part of the growing season, following a late fall or early spring application. Sharrat et al. (1962) reported that whey was effective in increasing corn yields in the first and second growing season after application. He also found that, one-season application of whey at more than 4 acre-inches may supply sufficient salts to temporarily inhibit plant growth. He observed that the protein in whey was readily

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Table I. Chemical Composition of Whey Used for Land Spreading Experiments, University of Wisconsin—Arlington Experimental Farm, 1972[a]

sample	P, %	K, %	Ca, %	Mg, %	Na, %
1	0.93	3.92	0.64	0.19	1.09
2	1.22	1.58	0.43	0.08	1.47
3	1.39	1.47	0.39	0.12	0.40
4	1.37	3.94	0.95	0.19	1.25
5	1.18	5.17	0.91	0.17	2.77
av	1.22	3.22	0.66	0.15	1.40

[a] Analysis given on basis of dried whey solids, which comprise about 6% of fluid whey.

Table II. Average Corn Yields (bu/Acre at 15.5% moisture) from Whey Treated[a] Plots at University of Wisconsin—Arlington Experimental Farm

	inches[b] of whey applied				
year	0	4	8	16	32
1973	68.5	168.8	178.3	156.7	0
1974[c]	29.9	65.4	75.4	48.4	39.1
1975	60.3	131.9	152.8	138.5	40.1
1976[c]	24.5	41.9	58.1	71.5	72.0
1977[d]	35.4	71.8	135.6	137.1	165.8
av	43.7	95.9	120.4	109.3	63.4

[a] Whey applied in fall of 1972 and spring 1973. [b] One acre-inch is approximately 28 000 gal. [c] Extremely poor corn growing years. [d] Starter fertilizer (200 lb of 6-24-24/A) drilled at planting on all treatments.

converted to nitrate. A beneficial effect on the soil's physical condition was also reported by Sharrat et al.

FIELD EXPERIMENTS

University of Wisconsin—Arlington Experimental Farm. To determine the effect of spreading whey on land, varying amounts of whey were applied on small replicated plots (225 ft^2). The project was based at the University Experimental Farm, Arlington, WI. The whey was applied to row crop and sod land on prairie Plano silt loam soil (Typic Argiudoll). Zero, 4, 8, or 16 in. of whey were applied on separate plots in the fall of 1972 and again in the spring of 1973, with one set of plots receiving an application both times (Watson et al., 1977). These were the only applications of whey made and the reported data herein reflect the effects of these doses.

The chemical composition of the whey used at Arlington, as shown in Table I, is rather typical of sweet whey. The average phosphorus and potassium content was 1.22% and 3.22%, respectively.

The whey was also analyzed for Al, Fe, B, Cu, Zn, Mn, and Cr and showed low concentrations of these elements which is typical for whey. These minor elements, in low concentrations, would have no significant impact on the soils and, therefore, received no further consideration.

Corn has been grown continually on these plots since 1972. The yields are given in Table II.

Note the substantial increase in yield in 1973, from the applications of 4, 8, and 16 in. of whey. Not only did the corn yield increase approximately 100 bushels/acre as compared to the control plots, but the corn leaves were of a deep dark green color, indicating an abundance of nitrogen throughout the growing season.

Tissue analyses from the 1977 crop listed in Table III indicate that all major nutrients are still being supplied in the sufficient range regardless of whey application. The consistent reduction in magnesium content with increased whey applications is to be expected since this cation usually decreases in concentration in tissue as potassium increases,

Table III. Results from Corn Leaf Analyses at University of Wisconsin—Arlington Experimental Farm 1977

	inches of whey applied				
	0	4	8	16	32
			Percent		
P	0.277	0.270	0.324	0.342	0.392
K	1.70	2.05	2.26	2.31	2.39
Ca	0.468	0.380	0.383	0.410	0.387
Mg	0.434	0.305	0.225	0.242	0.167
Na	0.01	0.01	0.01	0.02	0.03
			Parts per Million		
Al	57.9	44.0	49.0	49.1	44.3
Fe	111.0	112.0	127.0	140.0	146.0
B	6.08	5.07	6.05	7.63	9.45
Cu	7.67	8.38	10.6	12.4	9.31
Zn	15.8	17.5	38.2	59.8	125.00
Mn	32.9	37.2	151.0	176.0	381.00

though even at the highest K level Mg is still at sufficient levels.

All the minor elements are also present, in all tissues, in the sufficient range except zinc and manganese. The zinc amounts for the untreated and 4-in. applications are low though not deficient. Analyses above 75 ppm of manganese are considered high and the tissue from the plots receiving 8, 16, and 32 in. of whey are two–five times this amount; however no toxicity symptoms were visible.

The results from the analyses of corn leaf tissue, with the possible exception of manganese, fall into the ranges anticipated. The tissue analyses were done on corn plants grown at the Arlington Farm because the controls being used there were very exact. No tissue results are reported from Rupert because fertilizing with whey would most likely give similar results regardless of geographic location.

A review of the concentrations of the elements found in the tissue indicates that the use of whey for fertilizer may have some impact on the calcium–phosphorus balance in the corn grown. Even though this may be true, the concentrations in the leaves, even under maximum dosing conditions, are such that they are having no significant effect on the suitability of the crop for use as animal feed.

Similar tissue analyses on the corn and hay harvested from these plots in 1973 indicate that the uptake of secondary and micronutrients is relatively unaffected by whey application.

The soil test is used to indicate plant nutrient availability and is a standard for determining the need for applying additional plant nutrients. In this study we used phosphorus and potassium as indicators of nutrients available for crop growth because it is practically impossible to develop meaningful nutrient budgets for nitrogen without knowing what has been denitrified or leached. Crop uptake of nitrogen is negligible when compared to the total N applied at rates greater than 4 in. of whey/acre.

The soil analysis for the phosphorus, applied to the land in 1972 and/or 1973 and sampled in October 1974, is shown in Figure 1. The analysis of a similarly dosed plot sampled in June of 1977 is also given in the same figure. In Figures 1 and 2 the upper foot of the profile has been expanded because the P and K in whey will have the greatest impact on this portion of the soil profile. There has been very little downward movement of phosphorus below approximately 12 in. in the soil profile. Fifty pounds per acre of phosphorus is considered adequate for row crop production, but the soil is an almost inexhaustible sink for applications of excessive amounts of phosphorus. The iron and aluminum that are naturally present in the soil will tend to combine with phosphorus to remove it from so-

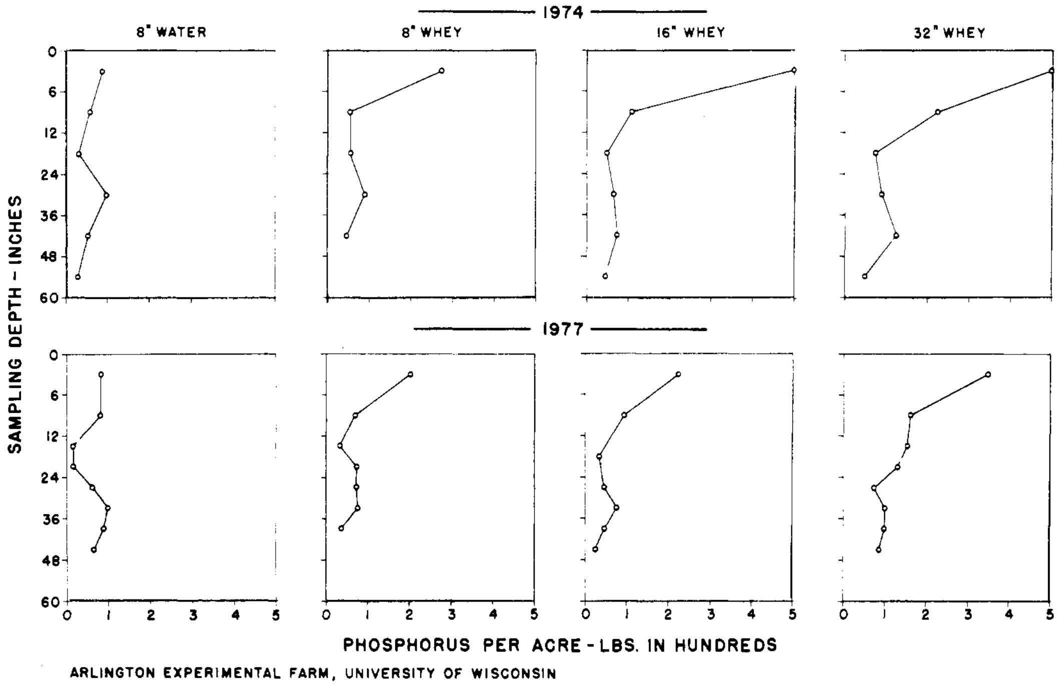

Figure 1. Whey spreading and phosphorus in fallow soil.

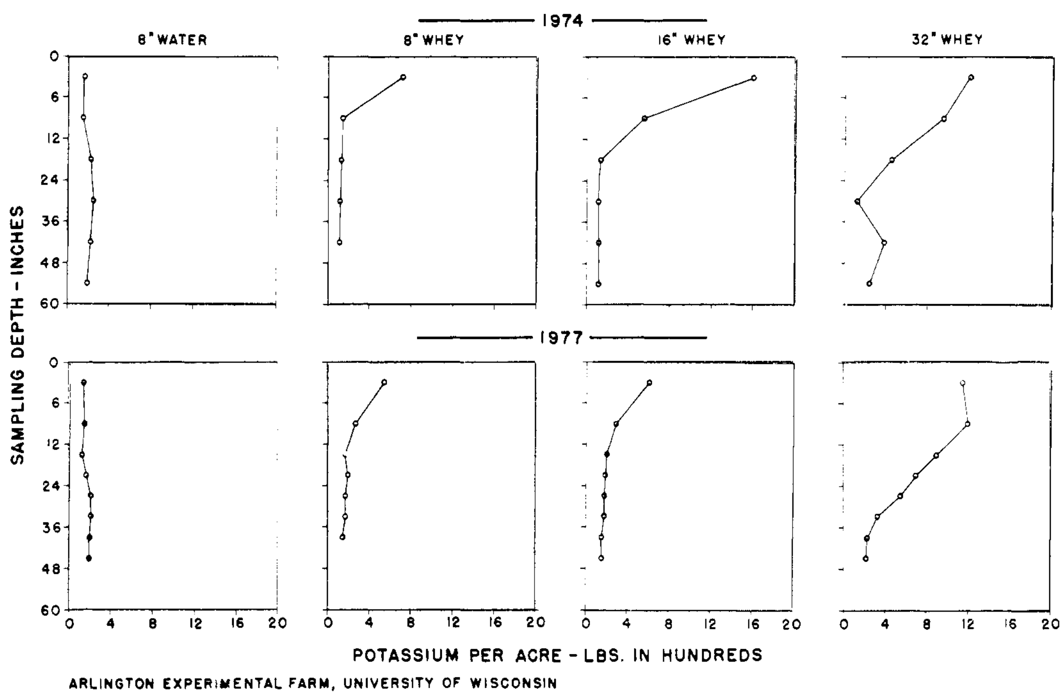

Figure 2. Whey spreading and potassium in fallow soil.

lution, and thus, no inhibitory effect on plant growth would be expected. Note that between 1974 and 1977 appreciable quantities of phosphorus were removed from the upper 12 in. of the profile by the corn grown on the plot.

The potassium levels in the soil are shown in Figure 2 and indicate very little downward movement of this element, except with excessive application of 32 in. of whey. The potassium will move down only after the exchange capacity of the soil is saturated, as shown in the 32-in. application where movement has occurred to a depth of 2.5 ft. Excessive amounts of potassium could cause other nutrient deficiencies to occur, as well as some salt problems. However, the 1977 analysis did not indicate any residual accumulation, nor was salt toxicity in the plants visible. Assuredly, a reservoir of potassium in this soil will be available to crops for years to come. Note that, as a general rule, less potassium was present in the top 12 in. of soil in 1977 than was present in 1974 and that corn was being grown on these plots.

The effect of whey application on water infiltration rates was determined using simulated rainfall produced by a sprinkling infiltrometer (Dixon and Peterson, 1968). A fourfold increase in the infiltration rate indicates that whey applications increase the porosity of the soil resulting in greater water retention. This usually benefits crop yields. Further, during rainy periods, the amount of runoff and, consequently, the amount of soil eroded from the land are greatly reduced.

Irrigation Site: Rupert, Idaho. This Rupert cheese plant produces Swiss cheese and Philadelphia cream cheese and more than 100 000 000 pounds of acid and sweet whey each year; whey disposal is a problem.

Table IV. Kraft Environmental Control Laboratory's Analyses of Well Water in Conjunction with the Rupert, Idaho Whey Irrigation Site

		above site[b]			irrigation site[c]			below site[d]		
parameter	whey[a]	6/11/73	7/3/73	10/9/74	6/11/73	7/3/73	10/9/74	6/11/73	7/3/73	10/9/74
BOD M/L	39440	1	1	1	1	1	1	1	1	2
COD M/L	75050	15	1	8	24	16	4	4	4	4
nitrogen M/L										
ammonia as N	117	0	0.1	0.1	0	0.1	0.1	0	0.1	0.1
Kjeldahl as N	1226	0.1	0.1	0.5	0.6	0.5	0.3	0.4	0.1	0.3
nitrate as N	3.55	1.75	2.1	1.0	0.9	0.4	1.0	1.45	0.6	1.1
nitrite as N	0.001	0.01	0.001	0.003	0.125	0.68	0.001	0.005	0.001	0.001
phosphate										
total as P M/L	390	0.10	0.059	0.092	0.14	0.417	0.080	0.10	0.26	0.052
ortho as P M/L	287		0.033	0.020		0.057	0.040		0.057	0.030
MPN Coliform		0	0	0	10.0	24.0	0	0	0	0

[a] Average concentrations for samples collected on 7/3/73 and 10/9/74. [b] Well about 0.5 mile north and west of the irrigation site. [c] Well on whey farm, north edge irrigation area. [d] Well 0.25 mile south and west of whey disposal area.

The cost of installing evaporation and drying equipment to dispose of the whey for this moderate-sized plant appeared excessive. The agricultural land in the area could benefit from both the water and plant nutrients contained in the whey since the average annual precipitation is only 10 in. and therefore crops are irrigated. However, continuous irrigation of undiluted whey directly on a crop could not be practiced without plant injury. Therefore, diluting the whey with the irrigation water normally applied on the and appeared worth trying.

The whey was diluted 1:8 with irrigation water and applied to the land with overland, self-propelled equipment. The fescue grass grown on this field is used for grazing cattle or is removed as hay. This field was first cleared for use in 1971. During periods of inclement weather, primarily in winter months, irrigation is difficult, so a reservoir is used to hold the whey temporarily.

Analyses of the phosphorus and potassium of the soil from the treated and untreated areas were made by the University of Wisconsin—Madison. Soil samples taken in both 1973 and 1974 show a surprising downward movement of phosphorus below the 12-in. depth. A great reduction in phosphorus content was noted beyond the depth of 30 in. which for most crops comprises full-rooting depth.

The potassium contents of the Rupert soils, sampled in both 1973 and 1974, are quite high in the control samples though still greater amounts were found in both the 1973 and 1974 samples from the whey-treated areas. At these potassium levels plant growth was not hampered because the potassium moves down once the soil's exchange capacity is saturated.

Only one-half to two-thirds the amount of potassium found in 1973 was obtained in the 1974 sampling, which may be due to a different sampling site. Such variations within a field are not unusual.

The effect on ground water when whey is applied to the soil was determined by sampling three wells in and near the Rupert field. They were located above the irrigation site, underlying the site, and downstream from it and were drilled to a general depth of 150 ft.

The analytical results from the three sets of samples from the three walls, along with average whey results, are summarized in Table IV. The variation for the three sampling points, parameters that could be affected by whey irrigation, fall well within the range of experimental error. These reports suggest that whey irrigation has no impact on the ground water table on this field. Conditions found at Rupert do not necessarily represent all other areas; but, if the land is used to grow crops, the nutrients in whey will probably remain in the root zone area and have little effect on deep ground water tables.

Clare, Michigan: Land Spreading Site. This plant produces Colby cheese and more than 50 000 000 lb annually of sweet, fluid whey. Since the early operating days of the plant, a whey storage tank has been provided and area farmers have been encouraged to feed this whey to their farm animals. It is free for the hauling. This use of whey has been growing, with about 50% of the 1976 production being fed to animals.

Since the cost of equipment for condensing and drying whey appeared excessive, other methods for disposing of the remaining whey were sought. About 40 acres of farmland was purchased in 1955 to serve as a whey disposal site. Through the years hay crops (primarily timothy, quack, and brome grass) have been harvested, but not on a regular basis. In recent years the plant has paid an annual environmental surveillance fee to the Michigan Department of Natural Resources and periodic inspections of the site are made by agency personnel.

Storage of the whey is not a problem since trucking to the disposal site is a year-round operation. The whey is hauled in a tank truck and dosed from a perforated pipe mounted on the rear of the truck.

Phosphorus and potassium analyses of the soil to a depth of greater than 5 ft, as sampled in 1973, indicate that movement down to 30 in. is occurring at one site, whereas movement down to 18 in. is occurring at another site. This again shows that the soil is serving as a sink and is preventing downward movement of appreciable amounts of phosphorus.

The 1974 sampling indicates a larger buildup and downward movement to nearly 5 ft in the earlier application area. This indicates that phosphorus contents are increasing, though even after 20 years of application, it has not inhibited crop production. Since no effort has been made to log the quantity of whey applied to any particular portion of the irrigation field, the exact relationship between the earlier and recent sampling sites could not be established.

The potassium has moved down the soils, sampled in 1973, to a considerably greater depth than has the phosphorus. This would indicate that the soil's exchange capacity is becoming saturated, as the potassium has moved down to a depth of 72 in. The 1974 samplings indicate a movement of potassium down at least 60 in. and a greater buildup in the upper 12 in. This indicates that potassium is moving down the profile and may eventually reach the ground water. Potassium, in the general concentration range indicated, is not considered a serious water pollutant by the regulatory agencies. Note that the controls contained an appreciable potassium residual down to the 30-in. level in 1973 and ran the full depth of the profile in 1974.

SUMMARY

Whey application directly on cropland, either by truck-spreading or irrigation, has shown that the plant nutrients contained in the whey will be beneficial for growing crops requiring nitrogen as indicated by crop yield and tissue analysis. The buildup of phosphorus and potassium in the soil is in direct proportion to the amount of whey applied, and results show that the soil acts as a vast sink for holding these nutrients until required for further crop production. The initial project, confirmed by the additional work reported here, showed that the plant nutrients in whey sometimes move down into the soil beyond the principal root zone. In the profile sampling of the spreading sites, occasionally to a depth of 9 ft, the likelihood of soil nutrients passing through the examined zones into the ground water does not appear significant. A brief examination of the underlying ground water at Rupert confirmed that there was no observable effect.

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Industrial Whey Processing Technology: An Overview

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This review deals with industrially applicable whey processing techniques suitable for utilization of whey for human food. Production of whey protein concentrates, dairy blends, lactose-hydrolyzed syrups, and certain consumer products from whey is briefly discussed. Compositional data for some of the new products are presented to indicate the diversity of their physicochemical properties. Industrial acceptance of the new molecular separation and modification techniques is documented.

Manufacture of cheese, cottage cheese, or industrial casein results in production of up to 9 kg of liquid whey for every kilogram of the final product. If this whey is dumped down the drain—a practice still common with many dairy processors—it constitutes the most potent of all dairy wastes (Orchard, 1972) and one of the strongest wastes of any kind (Table I). One hundred kilograms of liquid whey, containing approximately 3.5 kg of biological oxygen demand (BOD) and 6.8 kg of chemical oxygen demand (COD), has the polluting strength equivalent to sewage produced by 45 people (Webb and Whittier, 1970).

Yet, this so called waste contains about 20% of the milk protein, almost all of the milk sugar, and altogether about 50% of all the nutrients consumed normally in milk. In terms of proximate composition, mineral and vitamin content, and food energy, the dried whey solids can be compared with whole wheat flour (Table II).

The industrial recovery of whey nutrients for human consumption depends on availability of technically feasible and economically attractive processes, leading to marketable products. The objective of this paper is to review briefly some of the currently available technologies used in processing of whey for food as an alternative to waste treatment. The review will emphasize the processes that are being commercially exploited or are on the verge of industrial feasibility, including certain new developments in New Zealand and Australia noted during a personal visit in 1977.

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Table I. Characteristics of Food Processing Wastes (Orientation Values, Data from Various Sources)

	BOD_5, mg/L
dairy processing waste waters	
fluid milk plant	1000
ice cream plant	2500
cottage cheese plant	6000
whey powder plant	40
other food processing waste waters	
sweet goods bakery	2500
meat canning	1500
candy plant	4000
poultry processing	5000
raw wastes	
sweet whey	35000
acid whey	45000
fish processing stickwater	50000
domestic sewage	300

TRADITIONAL PROCESSES

Recovery of total whey solids as ingredients for human foods or animal feeds has been the most usual approach taken by large industrial whey processors. In Wisconsin, one of the most important whey producing areas in North America, 78% of all sweet whey produced was dried (Groves, 1972). The available techniques include spray drying, roller drying, concentration to semisolid feed blocks, or production of sweetened condensed whey. Other

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