Benefits of spreading whey on agricultural land

Kenneth S. Watson
Kraftco Corp., Glenview, Ill.

Arthur E. Peterson, Richard D. Powell
University of Wisconsin, Madison

In today's era of proper concern for water pollution control, the dairy industry has been giving attention to pollution which can be caused by whey if it is not properly handled. The soundest method of preventing whey from creating a pollution problem is by recovering its constituents for use as feed and food supplements. Perhaps the biggest drawback to this approach, however, is that recovery costs cannot be justified by the value of products recovered.

The need to properly feed the world's growing population is becoming more evident. Hopefully, the value of the whey solids and by-products which can be recovered will increase so that regardless of economic conditions, these products will be an attractive food source.

In spite of the feasibility of recovering products from whey, all the nation's whey cannot be used in this manner. Small scattered cheese plants which cannot individually or jointly justify expenditures for condensing and drying facilities must have a satisfactory method of whey disposal to continue to contribute to the world's food supply.

PLANTS PRACTICING LAND DISPOSAL

The exact number of cheese plants which need to make use of land disposal of whey to remain in operation is not accurately known. This is particularly true of cottage cheese plants. Better information appears to be available for the remainder of the industry, however.

Based on information available from the Whey Products Institute,[1] 10.63 mil metric tons (23.44 bil lb) of fluid sweet-type whey was produced in the U. S. during 1972. For the same annual period, 2.13 mil metric tons (4.7 bil lb) of fluid, acid-type whey was also produced in the manufacture of cottage cheese. These quantities of whey were calculated from cheese production figures released by the Crop Reporting Board of the U. S. Department of Agriculture.[2] The relatively small quantity of acid whey resulting from the production of cream cheese is included in the sweet whey total as a result of the USDA method of classifying cheese production.

In accordance with another report of the Economic Research Service of the Department of Agriculture [3] about 43 percent of the small plants (less than 907 metric tons (2 mil lb) annually) and 16 percent of the medium sized plants (907 to 4.5 mil kg annually), other than those producing cottage cheese, depend upon feeding and spreading on land to dispose of their whey. Therefore, about 285 plants dispose of approximately 1 135 mil l (300 mil gal) of fluid, sweet whey annually by land spreading.[4] This means that on an average, each plant would dispose of whey in the range of less than 3 800 to 24 000 l/d (1 000 to 6 250 gal/day). Each of the approximately 45 plants classed as medium in size, which are using spreading, would dispose of roughly 47 000 l (12 500 gal) of fluid whey on an average day. In developing these estimates the assumption was made that 15 percent of the whey generated by plants practicing land disposal is used for feeding animals.

It is known that a few large plants also practice land disposal. Some other large plants irrigate whey after water dilution. In the case of the largest plant known to be using this technique, about 227 000 l/day (60 000 gal) of whey is diluted with water and irrigated through a pipe distribution and spray-head system.

TABLE I. Analysis of Whey Application Experiments, Arlington Experimental Farm, 1972.*

	Percent					mg/l						
Sample	P	K	Ca	Mg	Na	Al	Fe†	B	Cu	Zn†	Mn	Cr
1	0.93	3.92	0.64	0.19	1.09	49	25	4.8	12.2	32.2	2.0	3.0
2	1.22	1.58	0.43	0.08	1.47	89	716	7.3	6.0	600	10.0	3.0
3	1.39	1.47	0.39	0.12	0.40	87	253	6.6	26.5	269	7.4	3.0
4	1.37	3.94	0.95	0.19	1.25	78	146	3.8	14.5	35	2.0	3.0
5	1.18	5.17	0.91	0.17	2.77	59	918	13.0	6.1	600	11.5	3.0

* Analysis given on basis of dried solids, which ranged from 5–6 percent by weight.
† Contamination from rusting galvanized iron tanks make the iron and zinc content excessive.

Accurate estimates do not appear to be available on acid-type or cottage cheese whey being spread on land. Since there are roughly as many plants which produce cheese other than cottage as there are those which produce cottage cheese, and more of the total plants of the latter type are classified as large, there may perhaps be about 100 plants in the U. S. which dispose of cottage cheese whey on land.

FIELD EXPERIMENTS

In this project the Soil Science Department of the University of Wisconsin, Madison, conducted field studies to determine the effects spreading whey on land would have on the mineral content of the soil, its permeability, and the crops which this soil would produce. Further, the effect that the whey might have on potential soil erosion was tested. This project was carried out by applying 51, 102, 203, and 406 mm (2, 4, 8, and 16 in.) of fluid whey to Plano (prairie) silt loam soil at the University Experimental Farm, Arlington, Wisconsin, with corn being grown as an indicator crop. Similar work was also carried out on sod or meadow land at the same farm.

Soil type. The soil at this experimental site is of the Plano series and consists of a type which is deep, nearly level to sloping, dark-colored, and well-drained overlaying glacial till. The surface layer is black silt loam about 203 mm (8 in.) thick. The subsurface layer is friable, very dark grayish-brown silt loam about 203 mm thick. The sub-surface layer is friable, very dark grayish-brown silt loam about 127 mm (5 in.) thick. The subsoil, about 813 mm (32 in.) thick, is firm in the major part. The upper part is medium acid, yellowish-brown silt loam; the middle part is medium acid, dark-brown silty clay loam; and the lower part is neutral, dark-brown, light clay loam.

The underlying material is calcareous, friable, yellowish-brown sandy loam glacial till. Permeability is moderate, and the available moisture capacity is moderately high. The root zone extends to a depth of more than 0.9 m (3 ft). The soils are generally acid. Plano soils are suited to all general farm crops and to many special crops. They are among the best farming soils in the state and most of the acreage is used for cultivated crops. There are no serious limitations for rural or urban development. The main consideration in management is to maintain the organic-matter content and fertility and to preserve soil structure. This soil has no serious limitations. (Capability unit I-l; woodland group 12; reaction group 1; wildlife group 1).

Procedure. Applications were made in the fall of 1972 from whey produced in the making of mozzarella and provolone cheeses. The whey applied in the spring of 1973 was produced in making blue cheese. The individual plots used were 4.6 m (15 ft) square. A pumping and spraying system was used in spreading the whey on the fallow and sod land.

Daily applications of 25 mm (1 in.) of whey in 13 mm (0.5 in.) increments proved to be the best application rate on the fallow land. However rates up to 25 mm at a time were sometimes applied on sod land. In addition to applying the quantities of whey listed nothing was dosed on one control plot and 203 mm of water on another.

Complete analyses of five random whey samples are given in Table I. The soil moisture to a depth of 1.5 m (5 ft) was determined using the neutron probe.

Water infiltration rates, water and nutrient runoff were determined using simulated rainfall produced by the sprinkling infiltrometer developed at the University of Wisconsin. Duplicate sites were selected for each treatment, and each simulated rainfall (run) was for a 60-min duration at an intensity of about 121 mm/h (4.75 in.). Both dry (initial)

TABLE II. Corn Yields from Whey-Treated Plots.

Treatment	Yield, m^3/ha at 15.5 percent moisture			
	1973*	1974*	1974†	1974‡
Control	5.9	1.9	3.8	1.8
203 mm H_2O	6.5	0.7	1.0	2.0
102 mm Whey	14.7	4.4	7.6	6.8
203 mm Whey	15.5	5.8	5.7	6.4
406 mm Whey	13.7	6.3	3.4	0.7

* Treated in 1972 only.
† Treated in 1973 only.
‡ Treated in 1972 and 1973 only.

and wet (24 h later) runs were made on each treatment. These infiltration measurements reasonably duplicate the field conditions one would find with dry soil and also that of a very wet soil that would be the most susceptible to erosion.

The infiltrometer consists of a 3 875 l (1 000 gal) water supply tank and a pressure system that sprays water from a 2.7 m (9 ft) height at the rate of 118 mm/h (4.67 in.) on an area 3.7 m (12 ft) in diameter, the center of which is the measured area that is enclosed by a 1.2 m (4 ft) square steel plot frame which is 305 mm (12 in.) deep and driven into the ground 203 mm to prevent any lateral seepage. Water running off this plot area is accumulated by a vacuum system into a tank with a water stage recorder. Thus the application rate minus the runoff rate provides the infiltration rate.

Whey composition. The whey analysis given in Table I indicates its plant food value. Whey contains on the average 5 to 6 percent solids by weight, of which most are sugars. About 0.5 percent of these solids consist of the nutrients listed below. One centimeter hectare (one acre inch) will contain about:

Nitrogen	150 kg	Magnesium	5.5 kg
Phosphorus	50 kg	Sodium	54.5 kg
Potassium	182 kg	Chlorides	122.6 kg
Calcium	36 kg		

The fertilizer value of one centimeter hectare (one acre inch) is about $175 at current prices for commercial fertilizers.

CROP YIELD

Corn. As indicated in the previous section, corn was planted on plots in 1973 and in 1974 after treatment with whey. One way of measuring the effect of whey on corn production is to take grain yields at the end of the season. These grain yields are presented in Table II. The four columns in Table II indicate the yields in cubic meters per hectare at 15.5 percent grain moisture.

Initial observation of the data in the table would indicate that conditions must have been different in 1973 than in 1974. This is just simply a climatic difference showing that 1973 was a much better grain growing year than 1974, primarily in terms of precipitation. However, of more interest is the change within a year as a result of the treatment. It will be noted that in the first column (1973 yields) from plots which were treated the previous fall (fall of 1972), production up to as much as 6.3 m^3 (178 bushels) of corn grain was obtained with 203 mm of whey applied. This was obtained without supplemental fertilizer. This indicates that the whey had a very beneficial effect on the corn production. It is obvious that the whey was beneficial, because when 203 mm (8 in.) was applied to the soil it produced an additional 3.8 m^3 (110 bushels) over the control plot and 3.6 m^3 (103 bushels) over the 203 mm of water plot.

The effects of the residual of this 1972 treatment is presented in the second column, Table II, showing the yields in 1974 for those plots that were treated only in 1972. It will be observed that there is still some residual effect of the whey; however, it is not nearly as great as it was in the initial year after application. Yields continue to increase up through the 406 mm application.

In the third column, Table II, which indicates the 1974 yields after whey applications in 1973 only, there was a definite response; however, in this case the maximum yields occurred with the 102 mm whey application rather than at the 203 mm rate. This in part may have been caused by climatic differences affecting the yields, since it was drier in 1974 than it was in 1973. Salt effect may have had some bearing as indicated by the fact that the 406 mm whey application yields were much lower than those of the control plots.

The last column covers those plots that were treated in both 1972 and 1973. Here again the yields tend to increase with whey application. The highest yield occurred at the 102 mm rate. However, since this plot was treated both in 1972 and 1973 it would have had a total of 203 mm of whey applied. Although this is true, this combined application did not seem to depress the yields like the single 203 mm application shown in column three. Where

406 mm of whey was applied in both 1972 and 1973 as very depressed yield of only 0.28 m³ (8 bushels) of corn grain can be seen. This is most likely caused by the climate during the year and a high salt concentration in the soil.

One could hypothesize from this data that whey could be used very beneficially as a supplement to or a replacement for fertilizer. The application of even 102 mm of whey to a soil is seldom practiced. More likely 13 to 25 mm applications of whey would be used. However, work on this project does indicate that dosage under practical circumstances of as much as 102 mm of whey on fallow ground the year before planting could have a very beneficial effect in terms of yield.

Hay. Established legume grass plots were also treated with whey. The same amounts of whey were applied to these plots as were applied to the corn plots. One observation is that whenever 102 mm or more of whey was applied on the established hay crop, burning took place and no yields were obtained from those plots for the year of application. The succeeding year indicated the benefits of whey dosing as shown in Table III.

It will be noted that when whey was applied in 1972 the yields (column one, Table III) show that 102 mm of whey would produce over 3.6 metric tons (4 tons) of dry grass hay the year after application. Most noticeable in this set of plots was the fact that the legumes did not come back after the initial burn from the whey. The residual effects of the 1972 treatment are shown in the second column and there are some very definite residual effects and yields that continued to increase in terms of dry matter up to and including the 406 mm application of whey. The results of the 1973 application are in the last column and indicate that as much as 203 mm of whey could be applied with the initial burn occurring in the application year and beneficial results occur in the next year. Where 406 mm of whey was applied there was a very definite depression of the yield over the 203 mm application similar to the results of the 1972 application.

In supplemental plots throughout the state, 17 to 25 mm of whey was applied on grassland which indicated that there was no burn and that yields were increased by this approach.

PROFILE OF NUTRIENTS IN FALLOW SOIL

Nitrate nitrogen. The plots were sampled down to 1 524 mm (60 in.) in depth in October 1974. With one set of plots this was after 2 years of whey application and in those plots that were dosed in 1973 only 1 year of corn production. The profile of nitrate-nitrogen contents are portrayed in Figure 1.

Nitrate-nitrogen was selected as the nitrogen criterion for this project since it is the form directly used by plants. It is soluble and thus quantities not taken up by the crop could move with the water through the root zone. Eventually it could reach the ground water table.

It will be noted that in all the graphs of soil profiles (Figures 1 through 6) the scale for the top 305 mm of the curves has been expanded over that for the remainder.

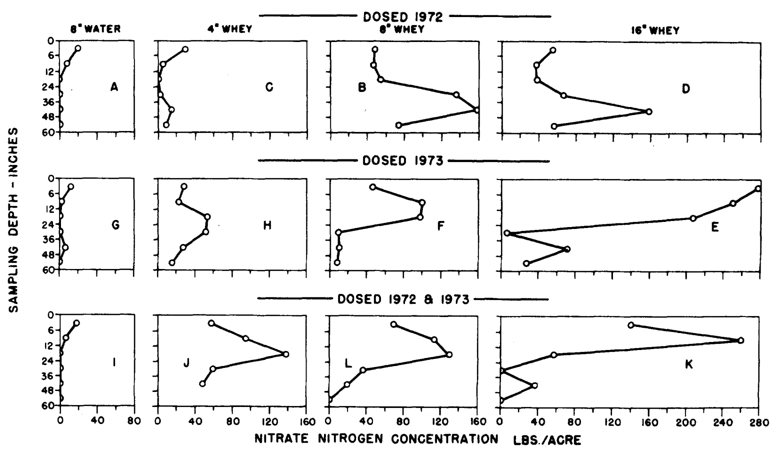

FIGURE 1. Whey spreading and nitrate nitrogen in fallow soil. (The letters indicate test plots.) in. × 2.54 = cm, lb/acre × 1.12 = kg/ha.

TABLE III. Hay Yields from Whey-Treated Plots.

Treatment	Yield, metric tons/ha dry matter		
	1973*	1974*	1974†
Control	6.3	4.9	6.3
203 mm H_2O	4.5	4.5	4.5
102 mm Whey	9.2	9.6	9.0
203 mm Whey	8.5	10.3	10.0
406 mm Whey	7.6	10.3	8.5

* Treated in 1972 only.
† Treated in 1973 only.

The data in Figure 1 indicated that in applying from 203 mm of water (1A) to 406 mm of whey (1D) a nitrate-nitrogen buildup within the soil profile took place. In the plots which were dosed in 1972 the nitrate-nitrogen has moved down into the profile to approximately a 910 to 1 220 mm depth, indicating that the crop does not remove all of the nitrate-nitrogen with applications of 203 to 406 mm of whey (1B & 1D). Even following 2 years of grain production, there still is an excess amount of nitrate-nitrogen at the 203 to 406 mm whey applications (1B & 1D). For those plots that were dosed in 1973, after a single year of application even at the 102 mm whey application rate (1H), there is an excess of nitrogen in the profile at the 610 to 910 mm (24 to 36 in.) depth. This does not seem to change except with intensity in passing to the 203 and 406 mm of whey application rates (1E & 1F). In other words, it has moved down approximately 0.9 m the first year after application and has not been removed by the crop.

Where the plots were treated in both 1972 and 1973, the effects of 203, 406, and 813 mm of total whey application (1I, J, K, & L) can be observed. The nitrate has not moved down in the profile beyond the 0.91 m (3 foot) depth, but the concentration is considerably higher at the 102 mm application rate (1J compared to 1H) and approximately the same in 1L and 1K, representing the application of 203 and 406 mm of whey for two successive years when compared to plots dosed in 1973 or 1F and 1E. It appears that even at the 102 mm application rate some of the nitrate-nitrogen is not being used by the crop (1J). However, as emphasized earlier, applications in the 17 to 25 mm range would be more practical and representative of actual practice. In using the data in this figure one could then hypothesize that through the application of 25 mm of whey the crop would remove most of the nitrate-nitrogen even if it was applied annually.

Phosphorus. The soil phosphorus levels are portrayed in Figure 2. It is apparent that there is very little downward movement of the phosphorus in the soil in the profile below approximately 305 mm. There appears to be one exception and this is 2E where there is a build-up of phosphorus at the 1 220 mm level. This build-up could be sampling error, old root channels, or a native soil phosphorus concentration in the profile. As with the nitrates, the higher rates of whey application gave higher rates of soil phosphorus and most of

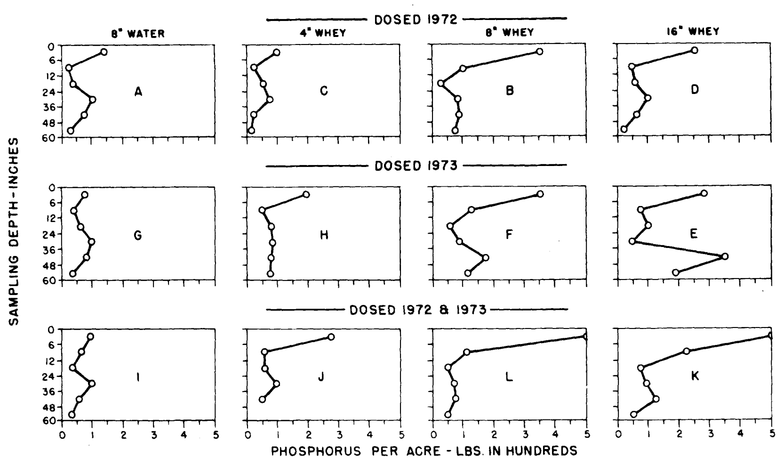

FIGURE 2. Whey spreading and phosphorus in fallow soil. (Letters indicate test plots.) in. × 2.54 = cm, lb/acre × 1.12 = kg/ha.

this soil phosphorus concentration is above the 300 to 610 mm depth. Phosphorus application in amounts less than 11.2 g/m^2 (100 lb/acre) is normal for this particular soil.

If a large amount of whey were spread in a particular year or amounts of consequence dosed in two succeeding years, it would be possible to charge the soil with phosphorus well in excess of 227 kg (500 lb). In this project, the crop was not removing the total amount of phosphorus applied and there was a phosphorus build-up. If rates such as used on these plots were used annually in practical applications, this might cause some micronutrient deficiencies in the crop. However, the project demonstrated that the soil is adequately retaining the phosphorus from the whey, and that little phosphorus is percolating through the soil to contaminate the ground water.

Potassium. The potassium levels of the soil are depicted in Figure 3 and show generally that there is a little movement of potassium down through the profile when single applications of 102 m of whey are made either 1 or 2 years prior to sampling (3C & 3H). The application of whey did increase the potassium levels in the soil surface up to as much as 67.3 g/m^2 (600 lb/acre) with the 406 mm of whey (3D) when it was dosed in 1972. Increases in the rates of whey application also increased the soil potassium content in the surface layer as demonstrated for 1973 by passing from plots 3G to E. Where whey was applied both in 1972 and 1973 (3I thru 3L), there was a build-up in potassium in the surface of the soil and also a downward movement of potassium to as much as the 914 mm level shown in 3K.

Test levels of 90.8 kg (200 lb) are normal in this soil and when application of 406 mm of whey either annually or in successive years are made, far more potassium than necessary has been applied to the land (3E & 3K). These high potassium rates could cause crop growth deficiencies to occur and some salt problems. In observing the 1974 grain yields there is a very definite effect here of the potassium and perhaps other salts concentrations 0.28 m^3 (8 bushels) of corn. Consequently, from the treatment portrayed in 3K (406 mm in successive years) this plot produced only on the yield.

PROFILE OF NUTRIENTS UNDER SOD

Nitrate-Nitrogen. The nitrate-nitrogen content in the soil profile is portrayed in Figure 4 where whey was applied to establish legume-grass sod. There is an increasing amount of nitrate-nitrogen at lower depths in the profile for 1972 as rates applied increase from the 203 mm of water treatment through 406 mm of whey; namely in 4M, O, and P. Since the plots were sampled in the fall of 1974 after whey application in the fall of 1972, effects noted were being observed after 2 years. At the 203 mm whey rate (4O) there is an excess of nitrate-nitrogen at the 610 mm depth indicating that the grass crop was able to remove the nitrate-nitrogen down as far as its rooting pattern had gone but a build-up below that level occurred. This is also indicated in the 406 mm whey application for 1972 (4P) in that grass was able to remove the nitrate-

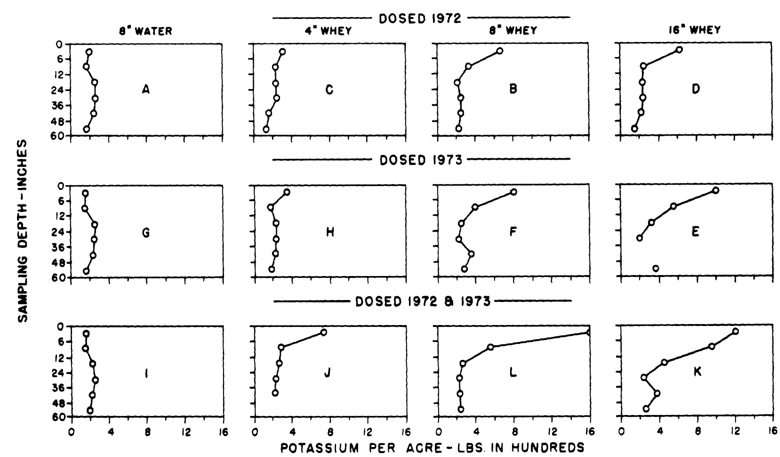

FIGURE 3. Whey spreading and potassium in fallow soil. (Letters indicate test plots.) in. × 2.54 = cm, lb/acre × 1.12 = kg/ha.

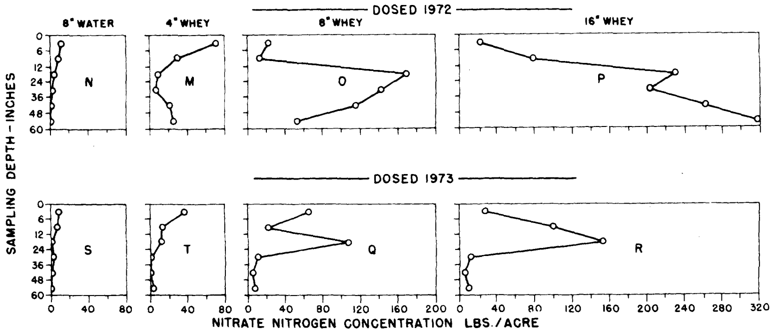

FIGURE 4. Whey spreading and nitrate nitrogen under sod. (Letters indicate test plots.) in. × 2.54 = cm, lb/acre × 1.12 = kg/ha.

nitrogen down to a depth of 305 mm but below that there was a substantial build-up.

Dosed plots from 1973 indicate much the same with one exception in that 4R does not show the build-up which occurred in 4P at depths below 610 mm. It is unclear why the higher nitrate-nitrogen concentrations occurred in 4P at depth below 910 mm. In 4Q and 4R there is a build-up of nitrate-nitrogen at approximately the 610 mm level indicating that the crop was not able to use all of the nitrate-nitrogen that was applied and that some excess had moved down as much as 610 mm into the profile. In the case of 1973 applications, observations were being made after a lapse of 16 months.

When comparing nitrate-nitrogen under sod, Figure 4, to that under corn, Figure 1, the concentrations in the soil under sod were generally lower than those under the corn crop indicating that the sod was able to take out more of the nitrate-nitrogen than the corn crop did. However, the rates of 203 to 406 mm of whey also exceeded the capability of the grass crop to remove the nitrate-nitrogen.

Phosphorus. The phosphorus concentrations in the soil profile under sod are portrayed in Figure 5. There was an increase in the surface concentrations of phosphorus as the rates of whey application increase. There was very little downward movement of phosphorus in the soil and consequently most of it is being retained in the top 305 mm of the profile. This would indicate that the soil is capable of retaining the phosphorus under application rates used. With the hay crop, the phosphorus levels increased to 28.1 g/m^2 (250 lb/acre) in the surface layer. This would be about 5 times the normal phosphorus level for these soils; however, concentrations were not high enough to indicate any nutritional problems. Those plots dosed in 1972 generally had a lower surface soil phosphorus concentration than those dosed in 1973 because of an added year of hay production. In other words, two seasons of hay production were obtained from the 1972 dosed plots but only hay from one season taken from the 1973 plots.

Potassium. The distribution of the soil potassium following whey application is portrayed in Figure 6. The data indicate that as the whey treatment rate increased, either for plots dosed in 1972 or those dosed in 1973, the surface concentrations of potassium tended to increase. A downward movement of potassium does not seem to occur when compared to the plots receiving 203 mm of water, (6N & S) except in 6P, where 406 mm of whey dosed in 1972 lead to an increase in soil potassium levels down to almost 610 mm. In 1973, however, 4R does not portray this same phenomenon so there may be some difference here because of native potassium levels of the soil in 4P.

INFILTRATION MEASUREMENTS

Figures 7 and 8 (and Table IV) give the average of duplicate infiltration measurements made in the fall of 1972 on fallow soil that had been treated with whey in June 1972. The highly significant four-fold increase in infiltration rates on both the dry and wet soil indicates that whey applications greatly benefited the soil structure and thus infiltration rate. This is especially important for the wet soil, since runoff and sediment loss are more serious from such soils.

The 1974 infiltration measurements are also summarized in Table IV. The first half of the quantity of whey was applied in August 1972 and a like amount dosed in May and June 1973. The double whey treatments which ap-

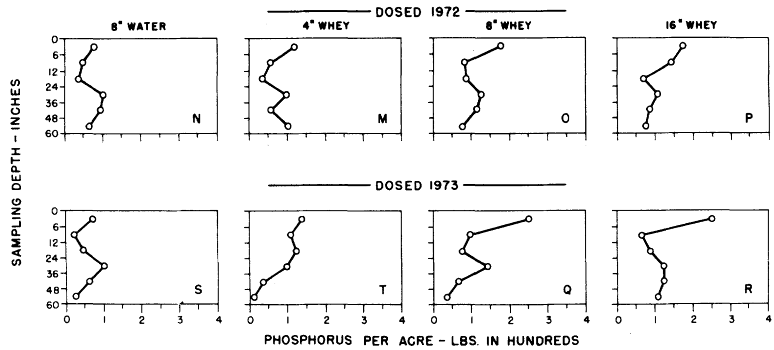

FIGURE 5. Whey spreading and phosphorus under sod. (Letters indicate test plots.) in. × 2.54 = cm, lb/acre × 1.12 = kg/ha.

plied a total of 406 mm or more (16 in. or more) of whey reduced infiltration as might be expected. The anaerobic conditions that were obvious upon examination of the soil also limited bacterial activity and reduced soil aggregation.

SUMMARY

As a result of looking at the test data for these treatments both for sod and fallow soil, it can be concluded that 102 mm of whey could be applied with benefits to crop growth and without any major problems occurring except for perhaps some downward movement of nitrate-nitrogen. The practicability, however, of applying 102 mm of whey to a field is limited, and a more common rate would probably be 17 to 25 mm. The rather high rates used leads to the conclusion that under normal full-scale application there would be very little downward movement of nitrate-nitrogen, phosphorus, or potassium. Thus the risk of pollution of the ground water table following whey application is slight.

Since, in the infiltration work completed, the water application rate exceeded the 50 year storm frequency of 61 mm/h, little if any runoff would occur from whey treated land under such an intensive storm. Retention of such storm water is important because the moisture becomes available for crop production and soil erosion is greatly reduced.

GUIDELINES FOR APPLYING WHEY ON LAND

A natural concluding step to the projects summarized is the development of a set of guidelines by which cheese plants can practice land disposal of whey to the mutual benefit of themselves and the farmers in the surrounding area. These guidelines can be applied where the quantity of whey is small enough so that the value of the whey solids and by-product that could be recovered will not finance the installation and operating costs of recovery facilities. Based on the experience gained from this project, guidelines for the use of whey on land will be outlined. Following

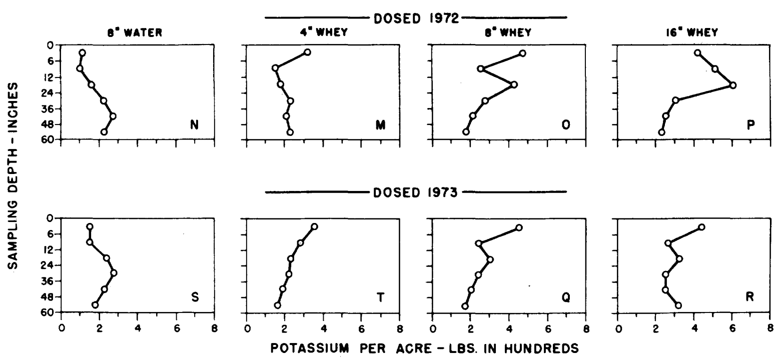

FIGURE 6. Whey spreading and potassium under sod. (Letters indicate test plots.) in. × 2.54 = cm, lb/acre × 1.12 = kg/ha.

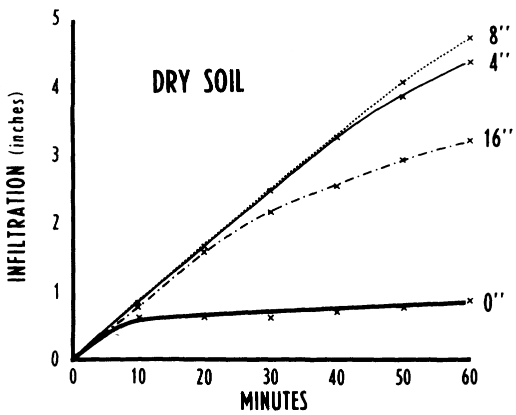

FIGURE 7. Effect of whey applications on water infiltration rates on fallow prairie soil.

these guidelines will not only provide nutrients needed for optimum crop growth but improve the soil structure as well.

1. Land disposal can be used on the fields of neighboring land owned or leased by the plant for the disposal of whey. The second approach is a less desirable alternative since practically no benefit will be obtained from the nutrients in the whey unless the crop is harvested and the nutrients removed from the soil. Some plants use the combined approach of spreading whey on farmland during most of the year but also owning a plot of land for whey disposal.

2. The use of a tank truck with a splash plate is recommended for dosing the fluid whey. Dosing will thus be achieved by driving along parallel routes on the field in question until it is properly covered. As a general rule, driving at low speed will permit about 0.5 centimeter hectares (0.5 acre inch) to be spread at a given time. Application on sod is generally easier since it provides better traction for the truck.

3. A storage tank or lagoon, consistent in capacity with a particular section of the country and its climate, is recommended to serve as a reservoir for fluid whey for those periods of heavy rain or snow when it is too difficult for the tank truck to be driven across the receiving field. This could also apply during the growing season when crop growth might prohibit the driving of the truck over the fields. If this impounding of whey should tend to create a fermentation problem, feeding low concentrations of toluene or formaldehyde into the storage facility will control the situation. When such action is taken, separate storage is desirable if whey is also being used for animal feed, although some whey thus treated has been fed without ill effects. A range of 10 to 50 mg/l has been proposed for formaldehyde. At the concentrations which will stabilize fermentation these chemicals will have no objectionable effects when spread on land. Effective concentrations can be established for any particular case on a trial-and-error basis by starting with a low dosage and increasing until fermentation is controlled.

4. Care much be exercised to dose the whey at a rate that will permit it to soak into the soil. On land of even, gentle slopes this will usually mean about 0.5 centimeter hectare (0.5 acre inch) per application on most silt loam soils. If it is desirable to dose a greater quantity than will soak in rapidly, this can be achieved by a second application.

5. Care must be exercised to dose the whey in such a manner that it cannot run off the surface and into the streams. This precaution may eliminate some fields which have too steep a grade, especially if they are of a heavy soil texture. Where there is concern that the whey could reach a stream, an earth dike could be provided along the section of the stream in question.

6. The optimum quantity of whey to be applied under various conditions will depend upon the type of crop to be grown. It is very desirable to use the whey for nitrogen-requiring crops such as grass or corn, since nitrogen is the most valuable portion of the whey. The

TABLE IV. Effect of Whey Application on Water Infiltration Rates on Prairie Soil.

Whey Applications	Infiltration, mm/h: Fall, 1972		Fall, 1974	
	Dry	Wet	Dry	Wet
None	22.4	9.4	48.0	25.9
102 mm	110.2	32.0	69.9	35.6
204 mm	119.4	80.0	52.3	31.5
408 mm	81.5	32.8	54.4	34.5
None	—	—	66.5	29.5
102 mm*	—	—	82.8	41.9
204 mm*	—	—	77.2	36.3
408 mm*	—	—	26.9	25.1

* Half applied in fall 1972, half applied in summer 1973.

nitrogen, phosphorus, and potassium required for 5.3 m^3 (150 bushels) of corn can be adequately supplied by the application of 1 centimeter hectare (1 acre inch) of whey. This means that the annual application of 25 mm on land continuously planted in corn would maintain or somewhat improve the fertility of that field. The amount of whey to be applied to meadow land or for hay crops would be dependent upon the potassium content of the soil. All the potassium needed from most hay fields of the hay and dairying regions of the U. S. could be supplied by 1 centimeter hectare of whey. The small amount applied would not have any adverse effect. This means that the annual application can be made at any time, except during rainy seasons or wintry weather.

If the amount of whey available is limited, amounts about half of that mentioned above could be applied beneficially and cover more acres of land. If it is desirable to apply more whey than optimum, then amounts up to 102 mm can be safely applied without danger of the nutrients causing any toxic effect to plant growth. Some surface burn will most likely occur, however, because of salt desiccation of the growing plant.

7. The application of whey improves the permeability of the soil. This characteristic makes the use of whey particularly beneficial on heavier textured soils. The improved permeability results in less runoff of rainfall during intense storms and thus reduces soil erosion and makes the water retained available for future use by the crop.

8. Land Capability Classes. The soils of the United States have been divided into 8 land capability classes. The classes I, II, and III are soils that are suitable for annual or intensive cultivation. Row crops are grown on the three capability classes and whey can be applied with little risk of nutrient losses on capability classes I and II. Row crops can be grown on capability class III providing conservation control practices have been followed. Thus conservation practices should be in effect if whey is being applied to capability class III. Capability class IV are soils that are cultivated occasionally and are generally in pasture land. Here application of whey could be highly beneficial since the grass will respond to the nitrogen in the whey, the sod will provide good surface for truck spreading, and the whey will soak rapidly into such an area. If the land has a wetness hazard, extreme care should be used in spreading whey.

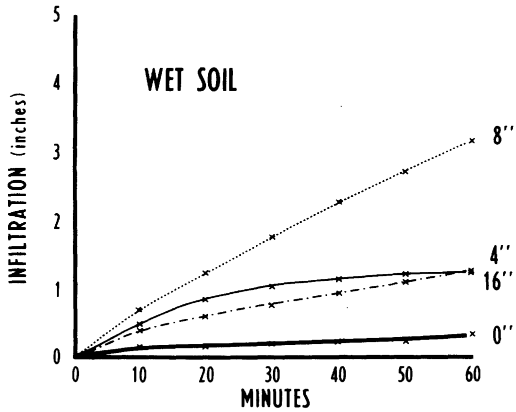

FIGURE 8. Effect of whey applications on water infiltration rates on fallow prairie soil.

9. For dosing on fallow land to be planted in corn or other grains, the applications can best be made in the fall following harvest when the soil is relatively dry or in the spring after the ground had dried sufficiently but ahead of plowing.

10. Dosing of meadow land can be carried out at any time, but spring or fall are somewhat preferred. If the dosing is to be practiced on land from which hay is to be cut in the summer or autumn, it should be done after the crop has been harvested. If some burning should occur as a result of hot, dry weather immediately after application, this temporary condition will soon disappear. Thus there is sufficient flexibility in the land disposal of whey so it can be readily fitted into the farmer's schedule of planting and harvesting crops.

11. As a general rule, application of whey on growing crops of grain should be avoided. In some cases, however, where crop lands require irrigation, the whey can be added to the irrigation water benefiting the crop and the land upon which it is grown.

12. The plant nutrients in whey can be classified as a complete fertilizer. Thus, it will usually not be necessary to add any supplementary fertilizer during years when whey in adequate quantity is applied for growing corn or hay.

13. Well drained soils are best for applications of whey. This means that the sandy loams, loams, and silt loam soils will be preferable. Most of the agricultural lands in the United States are well drained and thus whey application would be beneficial.

ACKNOWLEDGMENTS

Credits. The authors express appreciation to Kraftco Corporation for financial support of this project and to the University of Wisconsin for carrying out the work.

Authors. Kenneth S. Watson is Director of Environmental Control, Kraftco Corporation, Glenview, Ill. Arthur E. Peterson and Richard D. Powell are, respectively, Professor of Soil Science and Extension Soil Scientist, College of Agriculture & Life Sciences, University of Wisconsin, Madison.

REFERENCES

1. Private Correspondence, Whey Products Institute (1975).
2. Production of Manufactured Dairy Products, Crop Reporting Board, SRS, USDA, Da 2-1, 74 (1973).
3. Harold W. Lough, "The Cheese Industry." Economic Research Service, USDA, Agricultural Economic Report No. 294 (July 1975).
4. "Dairy Products." Crop Reporting Board, SRS, USDA, Da 2-6 (2-74).
5. Sharratt, W. J., *et al.* "Whey as a Source of Plant Nutrients and its Effect on the Soil." *Journ. of Dairy Sci.,* **42,** 1126 (1959).