THE PRODUCTION COMPOSITION AND UTILISATION OF WHEY, and OTHER PAPERS.

A THESIS

by

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NOTE OF EXPLANATION AND ACKNOWLEDGMENT.

This thesis embodies the results of investigations conducted during the academic years 1920-21 and 1921-22. The subjects were -

A. The Production composition and utilisation of Whey.
B. The Manurial properties of lead nitrate.
C. The effect of frequent changes of diet on the secretion and composition of cow's milk.

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C O N T E N T S

PRODUCTION, COMPOSITION and UTILISATION of WHEY.

A. THE PRODUCTION COMPOSITION AND UTILISATION OF WHEY.

Introduction

Whey is the liquid which drains from the curd produced by the action of rennet on milk, or from the curd formed by natural souring of milk, or by the addition to it of weak acids or other precipitants.

The concentration of cheese-making at factories in recent years has resulted in the production of large quantities of whey at centres where no adequate provision has been made for its disposal. Part of it is consumed as pig food. The remainder is discharged into streams and sewers. This involves a great waste of valuable food material. In many areas, to prevent contamination, discharge into streams is now prohibited. Sometimes it is irrigated on to the land as manure. On the farm practically all the whey produced is consumed as pig food.

Except on the lines indicated no attempt until recent years has been made in this country to exploit other outlets for factory whey. The problem is complicated by the fact that whey contains over 90% of its weight of water, it quickly decomposes and it is only produced in quantity during a few months of the year. A disposition to ignore the potential values of the milk sugar and the albumen which it contains further aggravates the position. The existence already in Great Britain of more than 350 milk factories and the number is rapidly increasing, is a reminder that the matter is one not only of urgency but also of considerable magnitude.

For the above reasons and also in view of the fact that there is almost a complete absence of published data respecting the production, composition and utilisation of factory whey in the United Kingdom, it was decided to make whey a subject for investigation. The work was confined mainly to the collection of data which entailed a great deal of chemical analyses, numerous visits to factories, considerable correspondence etc.

For convenience of treatment the subject is divided into the following three sections - 1. Production and waste; 2. Chemical composition, nutritive, manurial, market values etc., 3. utilisation.

Section 1.

PRODUCTION and WASTE

Whey is not included in agricultural returns. Neither is any record kept of its production at farm and factory, but reliable data respecting the quantity of milk converted into cheese and the weight of cheese made are available. Attention was therefore directed to these sources of information also to milk data contained in annual returns issued by the Board of Agriculture and the Ministry of Food.

The first point to be considered was the method of calculation of whey yields from milk data. In the manufacture of cheddar cheese[1] 100 gallons of milk on an average yields 100 lbs of curd (green cheese) and 90 gallons of whey. The yield however is subject to variation according to the composition of the milk and to the variety of cheese made. In addition certain losses occur during the process of manufacture, such as those caused by evaporation and waste from vats, tanks etc., and according to the skill shown in the manipulation of the curd. For these reasons it was decided to obtain figures representative of conditions of manufacture at typical cheese factories.

Accordingly arrangements were made to take at regular intervals during the cheese making season, weights of milk, cheese and whey at two factories in Ayrshire and at the Dairy School, Kilmarnock. At the dairy school

1. For outline of manufacture see page 14.

weights were taken one day each week commencing in the month of March and continued until the month of September. At the two factories weighings were made monthly. The results obtained have been summarised and the average figures representative of each centre are shown below.

	Dairy School	Factory 2.	Factory 4.
	1 vat	6 vats	8 vats
Milk lbs............	600	3635	4354
Whey "	518	3266	3858
Cheese lbs..........	63.5	359.25	421
Cheese produced from milk %............	9.5	8.9	8.7
Whey do. do.......	90.5	91.1	91.3
Loss of whey %......	3.5	3.1	2.0

Milk includes starter added in the proportion of 0.5 gallons to 100 gallons of milk and rennet extract at the rate of 1 oz to 16 gallons of milk. Whey includes that obtained from the vat and cooler respectively, see page 14. The latter formed from 3 to 11% of the total. Loss of whey was arrived at by deducting the weight of cheese and whey from that of the milk and the difference expressed as percentage of the latter.

It is evident from the above figures that 100 lbs of milk under the conditions of cheese making at the Dairy School yields 90.5 lbs of whey; at Factory 2. 91.1 lbs and at Factory 4. 91.3 lbs. Average 90.9 lbs. Deducting an average loss of 3% the final figure is 88 lbs. In reply to a circular letter posted to a number of cheese factories in the West of Scotland asking for information on the same point, the average result worked out at 91.9%.

Turning next to the production of milk, Figures taken from estimates supplied by the Ministry of Food[1]. and from data abstracted from a census of the agricultural production of Scotland are tabulated below.

	1909/13		1918
England.......	1,044,652,000	galls	no record available
Scotland......	186,348,000	"	" " "
Great Britain.	1,231,000,000	"	955,000,000

(1) Kindly supplied in correspondence in 1921.

The decline in the yield of milk for 1918 compared with the 1913 average, was attributed mainly to a shortage of feeding stuffs brought about by the war. As the yield is now increased again, the 1913 figures in absence of more recent ones are taken as being as near an approximation to the present production, as it was possible to attain.

From the same source the quantity of milk used for cheese-making was also obtained. The figures are given below, also their equivalent in whey calculated on the basis already formulated.

	Milk 1909/13	Whey
England.......	70,400,000 gallons	63,400,000 gallons
Scotland......	19,200,000 "	17,300,000 "
Great Britain.	89,600,000 "	80,700,000 "

Based upon the foregoing figures, the proportion of milk converted into cheese in England works out at about 6.7% of the total milk produced, and in Scotland to about 10.3%. It is also calculated that the latter country produces about 22% of the cheese manufactured in Great Britain. Of this amount over 90%[1] is made in the nine Western and South Western Counties. These Counties, it is also found, provide over 50% of the milk produced in the Country.

Before leaving this particular section it is hardly necessary to remark that the figures given are only approximations. Yet they serve their purpose in that they provide a basis for arriving at an estimate of the relative magnitude of the subject under review.

Information was next required respecting the distribution of Cheese-making between Farm and Factory. According to records of cheese-makers who operated under the British cheese distribution scheme during the period of control, the number of farms making cheese in the West and South Western Counties of Scotland, including the Hebrides, was 760[2]. Other estimates supplied by cheese merchants put the number at 800.[3]

(1) Census of Agricultural production in Scotland 1913.
(2) Kindly supplied in correspondence from Ministry of Food.
(3) Messrs Andrew Clement & Sons, Glasgow, and Messrs John Templeton & Sons, Kilmarnock.

To obtain definite data respecting the cheese and whey production of individual farms a circular letter asking for the required information was posted to 736 addresses. The replies received numbered 274. These were tabulated and a summary is set out below.

Average number of cows in herd..............	62	
Average yield of milk per cow for cheese-making season only......................	461	galls
Average yield of whey per day per farm......	113	"
Average total yield of whey per farm per season..............................	25,840	"
Average length of cheese making season...	227	days

Inspection of the tabulated results showed that the smallest herd consisted of 10 and the largest **of 150** cows. The lowest average yield of milk per cow per cheese-making season was 232 gallons and the highest 800. The lowest average daily yield of whey per farm was 12 gallons and the highest 326. The smallest total yield per season per farm was 630 gallons and the highest 84,240. The shortest season was 60 days and the longest 325.

As a basis for calculating total yields of whey from this particular source the above figures were unreliable as many of the farms from which no information was forthcoming, send their milk to cheese factories. In other respects they constitute very useful data.

As regards Milk Factories[1] no complete list of these were available and the information had to be obtained by correspondence. As a result there appears to be 48 milk factories in existence, several are under construction whilst others are contemplated. Their distribution between different proprietors and Counties is summarised as follows:-

Proprietors -		%
Co-operative Dairy Farmers Associations.	24	50.0
Scottish Wholesale Co-operative Society.	7	14.6
United Creameries Ltd..................	4	8.3
Private companies and individuals.......	13	27.1
Total	48	100.0

(1) Milk depot, creamery or cheese factory; milk depot is a collecting and distributing centre; Creamery was the designation applied to the first erected factories when butter and cream formed the principal articles for sale. The term is now applied to a milk depot which is also a cheese factory.

Counties of -
Ayr 17, Wigtown 11, Aberdeen 5, Kirkcudbright 3, Dumfries 2, Argyll 2. One each in Counties of Elgin, Inverness, Forfar, Perth, Stirling, Edinburgh, Peebles and Lanark.

A full designation of each with date of erection is given in the list below:

List of Milk Factories in Scotland

County of	Name					Date of Erection
	A. Affiliated with the Scottish Agricultural Organisation Society.					
Ayr	Rowallan Co-operative	Dairy	Farmers	Assocn Ld.		1908
"	Kilmaurs "	"	"	"		1909
"	Stewarton "	"	"	"		1910
"	Dunlop "	"	"	"		1908
"	Lugton "	"	"	"		1908
"	Galston "	"	"	"		1915
"	Fenwick "	"	"	"	Waterside	1911
"	Craigie & Symington	"	"	"		1919
"	Maybole & District	"	"	"	Kirkmichael	1920
"	Dalry "	"	"	"		1919
"	South Ayrshire	"	"	"	Pinwherry	1920
"	Upper Nithsdale	"	"	"		1919
"	Dunscore	"	"	"		1920
"	Lochilbo Road	"	"	"		1920
Kirkcud-	Dalbeattie & District	"	"	"		1920
bright.	Stewartry	"	"	"	Gatehouse	1921
Lanark	Lanark	"	"	"	Carluke	1920
Wigtown	Galloway Creamery				Stranraer	1920
"	Port William	"	"			1920
"	Newton-Stewart	"	"			1922
Inverness	Inverness	"	"			1912
Stirling	Strathendrick	"	"			1920
Argyll	Netherloan Dairy Association - Clachan Seil					1916
Aberdeen	Aberdeen Dairy & Central Milk Depot					1917

B./

B. Scottish Co-operative Wholesale Society Ltd.

Ayr	Rylands	Strathaven	1909
"	East Kilbride		
Wigtown	Whithorn		1902
"	Bladnock		1899
"	Sandhead		1896
"	Stranraer		1891
"	Drummore		1901

C. United Creameries Ltd.

Wigtown	Sorbie		1892
"	Tarf		1885
"	Colfin		1918
Argyll	Campbeltown		1919

D. Private Companies.

Ayr	Cumnock and District		1921
Peebles	Dolphinton		1920
Elgin	Elgin Creamery		1916
Perth	Perth "		1899
Dundee	Carse of Gowrie		1906
Edinburgh	Edinburgh & Dumfriesshire Dairy Coy Ltd.		1891
Kirkcud-bright.	Dalbeattie Creamery		
Dumfries	Kyle "	Dunscore	
"	Annandale	Dumfries	
Aberdeen	Keith Kennerty	Aberdeen	
"	Coulter	"	1896
"	Balgownie Dairy	"	1909
	Mellis & Son	Huntly	1899

The following summary of the dates of erection is interesting as showing the rate of progress in establishing milk factories in Scotland.

		%
up to 1907	12	27.9
1908/11	8	18.6
1912/14	1	2.3
1915/18	5	11.7
1919/22	17	39.5
Total	43	100.0

The increase within recent years is confined principally to milk factories belonging to the Co-operative Dairy Farmers Associations, membership of which it is claimed carries with it substantial advantages not possessed by individual farmers[1].

As already stated the primary function of a milk factory is to act as a centre for the collection and distribution of milk. The turnover in gallons of milk in 1920 for a number of factories is given in Table 1. below. The information was either abstracted from factory records or acquired by correspondence or taken from published balance sheets. Some declined to supply data. Figures for those recently erected are excluded from the table.

Table I.

	Milk Turnover in 1920.		
Milk Factory No.	Total Gallons	Used in Cheese-making Gallons	Percentage used in Cheese-making
1	504,769	230,762	45.7
2	896,229	278,759	31.1
3	640,000	90,000	14.1
4	563,557	52,300	9.3
5	468,102	159,895	34.2
6	1,132,594	573,301	50.5
7	500,000	29,320	5.8
8	534,332	146,210	27.4
9	482,025	311,227	64.6
10	600,000	100,000	16.6
12	360,000	260,000	72.2
18	600,000	400,000	66.6
25	665,107	205,479	30.9
26	662,000	422,704	63.8
27	1,121,942	615,599	54.9
28	585,841	9,480	1.6
29	517,742	465,346	89.8
30	910,000	606,667	66.6
33	665,725	150,897	22.7
35	756,958	412,538	54.5
37	310,000	45,000	14.5
43	400,000	120,000	30.0
Average	630,769	258,431	41.0

(1) These advantages are enumerated on page 10 Report Scottish Agricultural Organisation Society Ltd., Edinburgh 1920.

The largest turnover at any one centre amounted to 1,132,000 gallons and the smallest to 310,000, the average being over 600,000. From the data available it is calculated that about 29,000,000 gallons pass through these distributing centres. The amount works out at about 17% of the total milk production of Scotland. Owing to the absence of figures from some of the town factories with large turnovers, the estimate, in all probability, is below rather than above the actual figure.

The supply of milk in the summer months, is greater than is required for consumption; the surplus is manufactured into cheese. The proportion manufactured into cheese has been obtained for twenty two factories and the figures are given in Table I.page 11. The largest quantity employed for this purpose at any one factory was 615,000 gallons, the least being 9,500, whilst the average was 258,400. Expressed in percentages of the actual milk turnover, the proportion varied from 1.6 to 90.0, the average being 41.0. From correspondence it was learnt that in 1920 about 75% of the milk factories were making cheese.

Using the foregoing figures as a basis for calculation, the total volume of milk consumed in cheese making at factories in Scotland works out at about 9,300,000 gallons. The amount represents 48.0% of the total milk employed in cheese-making, including both farm and factory. The figures will vary from season to season.

The factory cheese-making season as a rule extends from the month of March to the month of September. The shortest period for which records were obtained in 1920 was 130 days and the longest 214, the average being 165 days. Only in exceptional circumstances is there surplus milk for cheese-making in winter. A few depots separate cream for butter making.

PRODUCTION OF WHEY

The yield of factory whey, equivalent to the milk figures was estimated to be as follows:-

Average production per factory per season	232,600 gallons
Highest yield at any one factory " "	554,040 "
Lowest " " " " " " "	8,500 "
Total yield of whey at factories in Scotland	8,372,000 "

The total production in Scotland approximates to 17,300,000 gallons, which according to the above showing is about equally divided between farm and factory.

Average daily yields of whey for season 1921 at four typical factories is shown on Table II.

Table II.

Average Daily Yield of Whey in Gallons.

	Factory			
	6	8	2	4
January	1494			
February	1538		604	
March	2205	316	927	
April	2988	1221	1116	27
May	3024	1053	1391	720
June	3204	1751	1593	832
July	2822	1800	1092	810
August	1478	1098	288	184
September	356	325		
October	277			
November	180			
December				
Milk made into Cheese % of Total	50.5	27.4	31.1	9.3
Whey produced per Season - Gallons	515,900	131,600	250,900	47,000

The figures are important inasmuch as they indicate the quantities for disposal daily at individual factories.

Waste of whey at Factories.

Only a few factories such as for example those situated close to the sea, or at the mouth of a river or where insignificant quantities of whey are produced, run the whole of it to waste. But the amount lost in this way represents only a small proportion of the waste which is taking place. The principal loss arises from the fact that although most of the factories utilise whey as pig food, the pig accommodation is entirely inadequate to allow for the disposal at the height of the cheese-making season of anything like the whole of the whey produced. For example as shown in figures Table II. p.13, the daily yield of whey from three to four months may amount to between 1000 and 3000 gallons. Assuming that a pig consumes from 3 to 4 gallons daily, it would require a herd of pigs of from 300 to 800 to dispose of it. So far as the author is aware, the largest piggeries would not hold more than about 300 pigs. It follows therefore that during certain months more than one half of the whey produced at many factories remains unconsumed.

Section II.

COMPOSITION AND PROPERTIES.

The next step in this investigation was to obtain data to show the composition of factory milk and whey and the extent to which both are subject to variation in the course of the cheese-making season. As already pointed out this was made necessary owing to the absence of data on the subject. As cheddar was the principal variety of cheese made, the work of this section was confined to a study of the whey produced from this source.

There are several stages in the process of manufacture and as each stage affects the composition and yield of whey, the following brief description of the process is given.

The first stage includes the "ripening", and the "coagulation" of milk. Ripening or souring consists in adding to the milk a culture[1] of a lactic acid producing organism, such as streptococcus lacticus, B. bulgarieus etc., the primary object being to convert milk sugar into lactic acid, temperature being a controlling factor. Theoretically milk sugar oxidises quantitatively to its equivalent in lactic acid, but small amounts of other acids are also produced. The acid dissolves some of the insoluble calcium compounds of the milk and produces a medium more favourable for the subsequent action of the rennet enzyme.

Coagulation is brought about by rennet added to the ripened milk. The rennet precipitates the casein which carries down most of the fat, part of the mineral constituents, and forms the curd or "coagulum". The serum or liquid portion constitutes the whey. The latter contains the milk sugar, albumen and any other protein not acted upon by the rennet, along with the remainder of the inorganic constituents and the fat. A concentration of about 0.22% of total acidity calculated in terms of lactic acid; a favourable temperature, a certain ratio of enzyme to volume of milk, and the presence of soluble calcium salts are conditions necessary to produce a suitable coagulation.

The second stage consists in cutting scalding or cooking of the curd. The curd which is left in contact with the whey gradually hardens; due to the action upon the physical condition of the protein, of acids and mineral salts. When sufficiently firm it is cut into small cubes and afterwards it is subjected to the operation of cooking and scalding. This consists in slowly raising the temperature until a maximum which is about 101°F is reached, the object being to further stiffen up the curd. When a desired degree of hardness is reached, the bulk of the whey (vat whey see p.24.) is drained off. During this stage slight peptic digestion of the curd goes on, the soluble nitrogen products formed pass into the whey.

The third stage consists in "cheddaring" and milling of the curd. By this is meant the curd from which the bulk of the whey has been drained, is piled

(1) A "starter".

along each side of the cheese vat and allowed to slowly cool, drainage of whey meantime going on. During this operation the acidity of the whey increases up to between 0.75 and 0.85% and the peptic digestion continues. The combined effect of the foregoing treatment is to materially alter the texture of the curd; the aim being to produce a foliated structure. The curd is then ready for milling and pressing. The yield of whey (cooler whey see p.6.) is small, and the amount draining from the cheese press is still less.

From the above brief description the general relationship between the composition of milk and the operations of cheese-making with the chemical content of whey should be manifest.

Different views are held in regard to the mechanism of the rennet action but it is not intended here either to enter into a discussion of these views or to attempt to give a summary of the vast amount of existing literature on the subject of milk and its constituents except in so far as it affords an explanation of any point which arises in the course of the present work. Considerable confusion, however, exists in respect to the nomenclature in use for casein and to which reference must be made.

From an historical stand-point it is of interest first to refer to the phraseology of milk constituents used by agricultural authorities in the early part of last century. The following example is typical of many recorded at that period[1]. "Milk consists of three substances mixed together, namely the oily or butter-aceous, the lactic or caseous and the serous or whey". Liebig[2] refers to the principal protein of milk as caseine or the cheesy matter and he does not differentiate between the casein in milk and that in curd. Hammersten[3] distinguishes between milk casein and curd casein. He holds that the rennet enzyme acts directly upon the milk casein producing two substances, an insoluble curd, para-casein,

(1) General view of the Agriculture of the County of Ayr by W. Aiton 1811 p.428.
(2) Animal chemistry by Baron Leibig Pt.1. 3rd Ed. 1846 p.54. also by same author. Familiar letters on chemistry 1859 p.373.
(3) Hammersten. Maly's Jahresb 1872 p.118;1874 p.135;1877 p.158.

and a soluble product, whey protein. He also showed that the change of casein to paracasein was independent of coagulation, the coagulation being due to the combination of paracasein with calcium to form an insoluble calcium paracasein (clot).

The nomenclature common in the United States and Europe is as follows - casein is the uncombined casein molecule; calcium casein or caseinate is the compound in milk and contains 1.5% of CaO[1]. Paracasein is the product formed from calcium caseinate by the action of rennet, and it is soluble in water. Calcium paracasein or paracaseinate is insoluble in water and is the clot or curd protein.

By some investigators caseinogen is the name given to the unchanged casein in milk and which corresponds to calcium caseinate. Casein and dyscaseose are names given to the rennet curd. Caseose is the whey protein.

Method of Experiment.

Samples of milk and the corresponding samples of whey from the vat and cooler respectively were taken once a week from the dairy school commencing in the month of March and continued until the month of September. Similar samples were taken monthly from factories 2 and 4.

The method of sampling was as follows:- The whey from the vat, for the purpose of weighing, was poured into a milk can. Each canfull after weighing was sampled and the different samples added together. From the mixture one litre was taken for analysis. Milk samples were obtained from the vats before renneting. The samples were conveyed to the Chemical Laboratory at the Dairy School where the analyses were immediately put under weigh. The determinations made in each sample include - total nitrogen, fat, milk sugar, ash, specific gravity, acidity and total solid. Total nitrogen was determined by Kyeldahl's method; fat by Gerber and the sugar by the Polariscope (Schmidt & Haensch). Every precaution was taken to eliminate experimental errors.

(1) Solder. Landw Versuchs-stat.1888 35.351. see also basic calcium caseinate. Van Slyke and Hart Am.Chem.Jour 1905, 33.461.

In order to test the reliability of the method of sampling, duplicate samples were at first taken and analysed. The results of duplicate determinations were found to be in close agreement.

Factory Milk.

The figures given in Tables III. & IV. (appendix) show the average monthly composition of the milk delivered to the Dairy School and to the two factories in question during the season 1921. The principal point of interest in these tables is the poor quality of the milk at the two factories compared with that supplied to the Dairy School. The contrast is brought out prominently in Table V. below which gives the average composition of the milk for the season.

Table V.

Average percentage composition of Factory Milk

	Dairy School	Factory 4.	Factory 2.	Average
Water...............	87.57	87.97	87.97	87.83
Protein[1]............	3.21	3.07	3.09	3.12
Fat.................	3.55	3.18	3.07	3.27
Milk Sugar Ash etc..	5.67	5.78	5.87	5.77
Total Solids........	12.43	12.03	12.03	12.16
Specific Gravity....	1.0320	1.0323	1.0323	1.0322
Acidity Total.......	0.20	0.18	0.17	0.184
Acidity[2]...........	0.10	0.09	0.07	0.084

As a rule milk employed for cheese-making in summer is from Spring calving cows and as the season progresses it shows a gradual change in composition in accordance with

(1) % Nitrogen x 6.38.
(2) After addition of potassium oxalate. Acidity is expressed in terms of lactic acid.

that produced as a result of an advancing lactation. The following figures Table[1]V/ illustrate the point.

Table VI.

Change in yield and composition of milk during lactation

Month	Milk yield in lbs Daily	Total Solids p.cent	Milk Fat p.cent	Solids not Fat p.cent	Protein (Total) % N x 6.38	Specific Gravity
April	32.1	12.37	3.5	8.87	3.18	1.0329
May	39.1	11.68	2.8	8.88	3.18	1.0318
June	34.8	12.25	3.3	8.95	3.24	1.0312
July	29.4	12.53	3.4	9.13	3.34	1.0315
August	26.6	12.63	3.5	9.13	3.58	1.0314
September	22.7	12.82	3.8	9.02	3.66	1.0311
October	19.1	13.38	4.3	9.08	3.88	1.0304

Except in the milk supplied to the dairy school there was no indication in the factory milk of any change similar to that shown in the above figures. In point of fact the total solids were if anything lower at the end than at the commencement of the season. The Summer was exceptional in that the rainfall was one of the lowest on record. However season did not appear to affect abnormally the composition of the milk supplied to the Dairy School.

Comparisons were then made of the yields and of the fat content of morning and evening milk. Below are representative data for each. They were arrived at by averaging a large number of figures obtained in an experiment on the feeding of dairy cows see p.74.

	Morning	Evening
Milk yield lbs..............	14.36	11.46
Fat %.......................	3.36	3.80
No. of tests................	896	896

(1) Berry R.A. Yield and composition of cow's milk during lactation. Bull 76 W. of Scot Ag. Coll. 1916 p.71.

The figures are confirmed by those of other investigators. Translated into words they mean that the morning milk which usually represents a longer interval between milking is poorer in fat but the yield is greater compared with that of the evening milk. It was afterwards found that at both factories morning milk only was made into cheese whilst at the Dairy School mixed morning and evening milk was employed. The above fact seems to explain satisfactorily the persistently low quality of the factory milk.

Ash in milk in the early part of the investigation was determined by direct ignition of the dry matter. Considerable difficulty was experienced in obtaining complete incineration and prolonged heating had to be resorted to. The results obtained were not consistent and the method was therefore modified see ash p. 29.

The average percentage of ash found was 0.71%. Partial analysis gave the following average results expressed in percentages.

	Milk	Ash
CaO	0.167	22.8
P_2O_5	0.219	30.1
MgO	0.021	2.9
K_2O	0.177	25.7

Season and stage of lactation affect the constitution of the ash as shown in the following results which were obtained in samples of milk taken in the course of the Summer.

Table VII.

Percentages of mineral constituents in milk and milk ash

	Milk			Ash	
	Ash	CaO.	P2O5	CaO.	P2O5.
May 3rd 1921	0.692	0.157	0.160	22.75	23.12
June 15 "	0.699	0.150	0.186	21.42	26.54
July 5th "	0.685	0.155	0.207	22.52	30.09
Average	0.692	0.154	0.184	22.23	26.58

According to the above figures the proportion of phosphoric acid in the ash increased as the season advanced.

A table to show the extreme variation of milk constituents in samples taken at the three centres throughout the season has also been drawn up and the figures are contained in Table VIII below.

TABLE VIII.

Variation in composition of Factory milk.

	Dairy School			Factory 4.			Factory 2.		
	Min.	Max.	Average.	Min.	Max.	Average.	Min.	Max.	Average.
Protein.....	3.02	3.50	3.26	2.81	3.31	3.06	2.89	3.31	3.10
Fat.........	3.35	3.95	3.55	3.00	3.30	3.18	2.80	3.20	3.07
Sugar & Ash.	5.48	5.37	5.62	6.03	5.61	5.79	5.96	5.90	5.86
Total Solids	11.85	12.82	12.43	11.84	12.22	12.03	11.65	12.41	12.03

The result is of interest inasmuch as the variations were high considering the milk was from mixed herds.

Casein and Albumen

Since albumen is the principal protein in whey and casein is one of the chief factors in determining cheese yields, it was considered necessary to obtain figures showing the proportion of each of these compounds present in factory milk. For this purpose milk supplied to the dairy school was employed. The amounts of each found at several periods are given below.

	Total Protein	Casein	Albumen[1].
May 24th 1921	3.30	2.79	0.51
July 5th "	3.03	2.61	0.42
Augt 2nd "	3.18	2.73	0.45
Average	3.17	2.71	0.46
May 1922	2.93	2.36	0.57
"	2.98	2.43	0.55
Average	2.96	2.39	0.56

(1) Includes Lacto-globulin, Fibrin.

The figures vary from those obtained by other authorities. For example Koenig[1] found the following average amounts. Casein 3.0, albumen 0.6%. Stocking[2] states the extreme limits of variation for each to be -

	Casein	Albumen
Maximum	6.29	1.44
Minimum	1.79	0.25
Mean	3.02	0.53

Total Protein 3.57%.

The figures quoted are for milk from mixed herds. It is however a well known fact that the protein content of milk varies from different breeds of cows and according to the period of lactation. Van Slyke[3] states the protein and albumen content of milk of well known breeds to be as follows:

	Casein	Albumen	Total Protein
Holstein	2.20	0.64	2.84
Ayrshire	2.46	0.61	3.07
Holderness	2.63	0.69	3.32
Shorthorn	2.79	0.64	3.43
Devon	3.16	0.83	3.93
Guernsey	2.91	0.65	3.56
Jersey	3.03	0.65	3.68

According to the Kilmarnock results and to the above it would appear that among the different breeds of cows with one exception the milk of the Ayrshire contains the lowest percentage of total protein. The effect of advancing lactation is to decrease the ratio of casein to albumen.

Having considered points in connection with the composition of factory milk which bear upon the composition of whey a brief study of whey is now taken up.

Whey.

For convenience the subject is considered under separate headings.

(1) Koenig. Chemie der mensch-Nahrung und Genussmittel.
(2) Stocking Manual of milk products 1920 p.19.
(3) Van Slyke & Publow. Science & Practice of cheese-making 1914 p.173.

General properties. Fresh whey possesses a faint greenish yellow colour, slightly opalescent varying with the amount of fat present. A yellow pigment named lactochrome has been isolated by Palmer & Coleridge[1]. which they state to be similar to "urochrome" the natural colouring matter of normal urine. Lactochrome is a minor pigment to "corotin" the chief colouring agent in milk.

In reference to colour the following quotation is suggestive[2].

"Go prick thy face and outrid thy fear
Thou lily-livered boy. What soldiers whey faced;"

Intensity of colour is affected greatly by the nature of the food, the carotin and Zanthophyll constituents of which being the principal source. The author observed marked changes in colour especially in the fat of milk as a result of substituting out-door for in-door feeding[3]. Breed, age of animal, lactation period[4]. etc. exercise but a slight influence on the colour of either milk or whey.

Like milk, whey possesses a characteristic odour. It is palatable and as judged by the following its consumption as human and cattle food dates back a considerable period.

"Down to the milk-house and drank three glasses of whey"[5].

"The whey is partly used as drink or made into a porridge with oatmeal which forms a wholesome, palatable and nutritious food. It is also fed to cows, horses and swine, much fine pork is raised from whey. The whey from three cows along with a very small supply of other food will raise a pig to a weight of between 10 and 20 stones from the months of April to December"[6].

(1) Yellow pigment of milk and whey. Palmer & Coleridge. Jour. Bio. Chem. XVIII p.251.
(2) Shakespeare Macbeth V.3.17.
(3) Berry Bull.76 p.57 ibid.
(4) Manual of Milk Products. Stocking 1920pp.85-91.
(5) Pepy's Diary 11.398.
(6) A Treatise on Dairy Husbandry. Aiton W. 1825 p.146.

On standing, a thin layer of fat separates, also a small sediment of curd settles out. On estimation the latter amounted to 0.02%. The whey becomes increasingly acid owing to the action on the milk sugar of lactic acid organisms. With concentration of acid albumen is precipitated causing the whey to become turbid and lumpy. (see p.28). In course of time the albumen undergoes partial decomposition with the result that the palatability and nutritive value of the whey suffers. The acidity obtained as a result of a number of tests, of the whey in the tank at the Dairy School and as fed to pigs varied from 0.5 to 1.0%. On boiling a flocculent precipitate of albumen separates.

Chemical Composition. A comparison is first made of the whey draining from the vat and cooler respectively. The average figures for the three centres are shown below.

	Vat	Cooler
	%	%
Water.............	93.17	92.83
Protein...........	0.87	0.94
Milk sugar........	4.80	4.48
Fat...............	0.21	0.33
Ash...............	0.48	0.59
Undetermined[1] & loss...........	0.47	0.83
Total Solids......	6.83	7.17
Acidity...........	0.18	0.22

(1) principally organic acids and their salts.

With the exception of the milk sugar, the percentage amounts of other constituents in the whey from the vat was consistently lower than that from the cooler. This difference for reasons given on page 15 was expected. The main consideration for the present, however, is the fact that the liquid from the vat forms the predominating component of cheese whey.

Before comparing the composition of whey obtained from the three centres a consideration of each constituent and the extent to which each is subject to variation during the cheese-making season, will be more profitable.

Constituents of Whey

Fat Contributes towards the nutritive value of whey. It can be separated and used as cream or it can be made into whey butter. As already pointed out the amount passing into the whey largely depends upon the skill employed in regulating the conditions of cheese-making such as temperatures, acidity etc., and in the cutting and manipulation of the curd. According to the figures shown below the fat content of whey appears to be independent of the amount present in milk; a result which is in harmony with that obtained by other investigators.

	Dairy School	Factory 4	Factory 2	Average
	%	%	%	%
Milk	3.55	3.18	3.07	3.26
Whey	0.26	0.16	0.28	0.23

Combining the three centres the extreme monthly limits of variation of the fat content are given in Table IX.

Table IX.

Variation of Fat in Whey - percentages.

	Minimum	Maximum	Average	Milk Average
April	0.12	0.29	0.20	3.36
May	0.19	0.36	0.21	3.38
June	0.16	0.27	0.22	3.39
July	0.16	0.30	0.22	3.30
August	0.16	0.24	0.22	3.68

As shown in the foregoing figures whey may contain as low as 0.12% and as high as 0.36%; a variation of 300% calculated on the lowest amount. This means that from 100 lbs of milk made into cheese 0.11 to 0.33 lbs (equivalent to 0.12 and 0.36% fat in whey) of milk fat passes into the whey. Expressed in percentages it works out to from 4.0 to 10.0% of fat in milk; the average being 7.0%.

The actual figures for the three factories are as follows:-

	Milk %	Whey %	Percentage of total milk fat passing into whey
Dairy School	3.55	0.24	6.7
Factory 4.	3.18	0.15	4.7
" 2.	3.07	0.25	8.1
Average	3.26	0.21	6.5

It is noticeable that the fat content of whey from Factory 4 is consistently lower than that from the other two. Fleischman and Van Slyke give the average percentage of fat in whey from whole milk cheese to be 0.35%. Koenig 0.32, Smetham 0.24, Warrington 0.3, and Richmond 0.25, compared with an average of 0.23[1] in the present case.

Nitrogen Compounds consist principally of albumen and to a small extent of a globulin and a caseose, along with any other introgen compound such as galactin, fibrin etc. which are stated to be present in milk and are not coagulated by rennet. They contribute towards the nutritive value of whey. Commercially they are of importance in that they can be precipitated, dried and used as articles of commerce either as a food stuff or for certain technical purposes or made into whey cheese (see page55).

Albumen was determined in three samples of whey with the following average result -

Albumen	0.56
Caseose etc.	0.31
Total	0.87

The average percentages of Protein in milk and whey at the three centres is shown below. Also that of the proportion of milk protein passing into whey.

	Dairy School	Factory 4.	Factory 2.	Average
Milk	3.21	3.07	3.09	
Whey	0.79	0.79	0.81	
$\frac{\text{Milk protein}}{\text{Whey protein}}$	24.6	25.7	26.2	

These figures bring out the point that the protein in whey at the three centres is fairly constant. Unlike fat the whey protein is not affected to the same extent by defective methods of manipulation of the curd. The extreme

(1) Includes figures for month of March & September, see p.25.

monthly variations is shown in Table below.

Table X.

Variation of protein in Whey.

	Protein in Milk %	Total Protein in Whey %. Minimum	Maximum	Average
April	3.09	0.82	0.89	0.85
May	3.25	0.82	0.91	0.87
June	3.28	0.86	0.93	0.89
July	3.07	0.82	0.95	0.88
August	2.88	0.84	0.88	0.86

The divergence between the highest and the lowest figure amounts to 8.6% calculated on the lowest.

The protein content of whey given by different authorities is as follows: Smetham 0.88%, Warrington 0.9%, Koenig 0.86%, Van Slyke 0.85%, Fleischman 1.0% compared with an average of 0.87%[1] obtained in this investigation.

Milk sugar forms the largest and principal constituent of whey. As already pointed out under favourable conditions certain organisms rapidly convert it into lactic acid. Other decomposition products are formed depending upon the type of fermentation. The fact that the accumulation of fermentation products is inhibitive to bacterial growth was used as a basis for an experiment designed to show the length of time it was possible to store whey in tanks without undue deterioration.

The experiment was as follows: Whey was kept in a 24 litre carboy and was sampled and tested for acidity and milk sugar at first daily, afterwards every seven days. Temperatures were also recorded. The results are given in Table XI below.

(1) Includes figures for month of March and September, see Table XIX. p.38.

Table XI.

Changes in Composition of Whey during storage.

Date	Number of days	Acidity	Acidity in presence of oxalate	Sugar	Average Temperature
		%	%	%	F°
20th Feby 1922.	0	0.144	0.111	4.94	58
21st "	1	0.45	0.435	4.61	56
22nd "	2	0.47	0.435	4.60	58
23rd "	3	0.47	0.435	4.55	59
24th "	4.	0.47	0.440	4.55	55
27th "	7	0.48	0.450	4.56	52
7th March	15	0.48	0.445	4.39	50
29th "	37	0.45	0.380	4.09	49
12th April	51	0.46	0.400	3.90	50
26th "	65	0.52	0.460	3.53	51
3rd May	72	0.56	0.495	3.25	54
11th "	80	0.64	0.50	2.82	56

In eighty days the milk sugar decreased from 4.94 to 2.82%. After the first 24 hours the destruction of sugar was slow but became more rapid towards the end of the test. This seemed to coincide with considerable growth of moulds and with brisk evolution of carbon dioxide gas. Almost from the commencement a thick scum collected on the surface which consisted of albumen upon which moulds were growing. From the odour it was evident a series of fermentation changes were in operation. The fact that acidity did not increase in proportion to the disappearance of the sugar indicated that carbonic acid was a principal decomposition product. Ammonia was also produced. The experiment proved conclusively that it was not possible to store whey at least at a temperature between 40° and 50°F. for many days without considerable deterioration.

Average percentages of sugar found in whey produced at the three centres is as follows:-

Dairy School	4.78%
Factory 4.	4.89%
" 2.	4.76%
Average	4.81%

The extreme limits of variation are given in Table XII.

Table XII.

Variation in percentage of Sugar in Whey

	Sugar in Milk %	Sugar in Whey % Minimum	Maximum	Average
April	4.86	4.62	4.88	4.71
May	4.81	4.74	4.89	4.83
June	4.86	4.85	5.01	4.88
July	4.72	4.64	4.87	4.78
August	4.53	4.67	4.72	4.69

From this table the minimum amount is 4.53 and the maximum 4.88%, a variation which is much less than that obtained for other constituents. As shown in Table XI age of whey is the factor which accounts principally for variation in sugar content.

Fleischman gives the average percentage of sugar in whey as 4.9, Koenig 4.8, Van Slyke 4.8 and Smetham 5.06.

Ash was determined by ignition of the dry matter and weighing the residue. Complete incineration by direct ignition was first made and as already pointed out the results obtained were not consistent. The dry matter was therefore charred, extracted with water, the residue burnt to ash. To this was added the filtrate, evaporated, ignited and weighed.

The average percentages found in the whey at the three centres is as follows:-

Dairy School	0.497
Factory 4.	0.515
" 2.	0.453
Average	0.488

The average of three determinations made in May 1922 was 0.53%.

In the samples from the Dairy School the amount increased as the season advanced. At the other centres there was a similar tendency though not so pronounced, see Table XX. appendix. Vieth gives the ash in whey as 0.54%, Koenig 0.65, Smetham 0.49 and Fleischman 0.60.

The extreme limits of variation found in these experiments are given in Table XIII.

Table XIII.

Variation in ash in whey.

	Ash in Whey %		
	Minimum	Maximum	Average
April	.398	.539	.471
May	.384	.649	.472
June	.366	.547	.463
July	.433	.511	.478
August	.480	.574	.532

The minimum amount is 0.366 and the maximum 0.649% ~~which~~ corresponds to a percentage variation amounting to about 77%.

Different views[1] are held as to the form of combination in which the inorganic constituents occur in milk and whey. The generally accepted view is that in fresh milk calcium exists in combination with casein, and as normal and acid salts of both phosphoric and citric acids. Magnesium and potassium occurs as salts of the same two acids, whilst the latter along with sodium are present as chlorides. Richmond states that casein exists in milk in combination with both calcium and sodium. As to the physical condition of the inorganic components of milk Van Slyke finds that the phosphates namely the calcium

(1) Trunz-zeit f.physiol-chem 40.263.1903; Solder. Landw Versuchs-stat 1888 p.351; Rona & Michaelis, Bio chem-zeits 21,114 1909; Van Slyke & Bosworth. Jour Bio Chem.Vol 20 p.135; Droop-Richmond Dairy Chem. 1920 pp.37 & 54.

and magnesium compounds are partly in solution and partly in colloidal suspension. The chlorides form a true solution. During souring of milk soluble lactates of calcium are produced from insoluble compounds of this element.

As regards the distribution of mineral constituents between milk and whey Richmond concludes that the bulk of the mineral salts pass into the whey. Van Slyke gives the proportion as 73% of the total mineral matter. Another estimate is that it amounts to three quarters of the total[1]. Of the phosphates of calcium it is stated that one third only appear in the whey[2]. In the present experiment it was found that 70.0% of the mineral constituents of milk passed into the whey.

Partial analyses of the ash were made with the following results:

	Whey	Ash
P2O5	0.119	22.4
CaO	0.066	12.5
MgO	0.017	3.3
K_2O	0.163	28.3

With advance of the lactation period slight increases in the amounts of lime and phosphoric acid occurred as shown in Table XIV below.

Table XIV.

Percentages of mineral constituents in Whey and Whey ash

	Whey			Ash	
	Ash	CaO.	P2O5.	CaO.	P2O5.
May 3rd 1921	0.560	0.060	0.108	10.63	19.28
June 15th "	0.538	0.063	0.112	11.77	20.71
July 5th "	0.564	0.069	0.116	12.67	20.26
Average	0.554	0.064	0.112	11.69	20.08

(1) Manette & Musso. Landw Versuchs-stat. 23.424.
(2) Standard encyclopedia of Modern Agriculture Vol. p.153.

The proportion of mineral constituents in 100 lbs of milk passing into the whey is; - lime, CaO. 36.0%; Phosphoric Acid, P_2O_5 49.0%; Magnesia MgO 75.0% and Potash K_2O 80.1%.

Acidity was determined by titration with $\frac{N}{9}$ caustic soda using phenol-pthalein as indicator. With this concentration one cubic centimetre of alkali is equivalent to 0.01 grams lactic acid, a convenient figure to use. The average figures for whey are shown in Table XV.

Table XV.

Acidity in Whey expressed in terms of lactic acid.

	Dairy School		Factory 2.		Factory 4.	
	Total	1.	Total	1.	Total	1.
April			0.167	0.129		
May	0.172	0.130	0.212	0.154	0.308	0.240
June	0.168	0.123	0.236	0.152	0.198	0.149
July	0.205	0.157	0.150	0.108	0.162	0.124
August	0.190	0.152	0.144	0.103	0.223	0.171
September	0.149	0.113	0.182	0.129		
Averages	0.177	0.135	0.182	0.129	0.223	0.171

1. After the addition of potassium oxalate.

Fresh milk is amphoteric in reaction, a property attributed to the presence of acid phosphates and to casein[1]. The acidity of fresh milk is partly due to the presence of these salts and to a less extent to carbonic acid and casein. In the titration of soluble phosphates such as disodium hydrogen phosphate which is neutral to phenol-pthalen, in presence of calcium salts, a di-calcium salt is formed. This immediately undergo hydrolysis into calcium hydroxide and phosphoric acid, the former unites at once with more of the di-calcium salt and forms a

(1) Second Report on Colloid Chemistry H.M.P.O. 1919 p.101.

tricalcium salt. As a result of these changes it requires more alkali to make a solution of acid phosphates neutral to phenol-pthalein in presence of soluble calcium salts, than it does without[1]. For this reason the acidity of whey determined by the ordinary method is high. To eliminate the error it is necessary before titration to remove soluble calcium salts by addition of potassium oxalate. In the present experiment titrations were made both before and after the removal of these salts. The difference between the two results provides an insight into the amount of soluble phosphates present in milk and whey. See Table XV above. Acidity of whey is due to free lactic acid, acid salts and carbonic acid.

Instead of caustic soda, lime water (calcium hydroxide), because of its cheapness, was tried. Also being sparingly soluble in water by having an excess of undissolved hydroxide, a saturated solution at the ordinary temperature of the laboratory was easily obtained. Saturated solutions prepared in this way from caustic lime secured from fourteen different sources gave a fairly uniform figure, namely a concentration of about $\frac{N}{20}$. When preparing the solutions, in order to remove salts of the alkali metals, it was found advisable to discard the first two saturated liquids made from the same sample of caustic lime. For this reason a large initial excess of lime was taken. When comparing the two solutions more lime than soda was required to neutralise both milk and whey, the figures being 0.16% of acid determined by soda and 0.19% acid using lime water. The difference is again due to the formation and subsequent hydrolysis of acid calcium phosphates during titration. The difference diminishes appreciably with an increase in the amount of acid present and it disappears entirely when the titration takes place in presence of added calcium chloride as shown in the following determinations.

NaOh	$Ca(OH)_2$	NaOH $CaCl_2$	$Ca(OH)_2$ $CaCl_2$
.13	.17	.22	.21
.16	.21	.25	.24
.38	.46	.48	.48
.43	.51	.52	.52

(1) Cause of acidity in fresh milk of cows and a method for the determination of acidity. Van Slyke & Bosworth. Jour Bio Chem. Vol.XIX. p.73.

Since farmers find it troublesome to obtain solutions of caustic soda of reliable strength for their acidity test details of a method and apparatus using lime water is in process of being worked out.

In connection with acidity it is of interest to refer to the fact that during coagulation of milk by rennet the acidity falls appreciably as shown in the following figures[1].

Just before rennet action milk	Just after whey	% decrease
.16	.10	37.5
.20	.13	35.0
.30	.21	30.0
.40	.28	30.0
.55	.38	30.9

Richmond[2] attributes the fall as being due to the splitting off from the casein molecule of sodium, which passes into the whey and neutralises an equivalent amount of acid, the casein left being neutral. According to Van Dam[3] there is no change in the hydrogen ion concentration during the action of rennet, whilst Michaelis & Mendlessohn find that the time required for coagulation with acids is proportional to the hydrion concentration. Other factors which influence acidity of milk and whey are - period of lactation, feeding and individuality[4].

The acidity of whey is important inasmuch as it influences the value of whey for the purpose of feeding and for the extraction of milk sugar.

Specific Gravity was determined at a temperature of 16°C in a specific gravity bottle, of every sample of milk and whey examined, and the result recorded. Average milk figures are given in Table III.& IV.in appendix. A summary of the whey figures is given in Table XVI. below.

(1) Berry. Bull 76 W.of Scot Ag.Coll. 1916 p.62.
(2) Richmond Dairy Chemistry p.55.
(3) Van Dam Zeit physiol Chem. 58.295 1908.
(4) Berry. Bull 76. p.62 ibid.

Table XVI.

Specific Gravity of Whey

	Specific Gravity of Milk	Specific Gravity of Whey		
		Dairy School	Factory 2.	Factory 4.
March	1.0310	1.0284		
April	1.0320	1.0284	1.0283	1.0277
May	1.0320	1.0281	1.0282	1.0280
June	1.0323	1.0283	1.0282	1.0281
July	1.0321	1.0283	1.0279	1.0282
August	1.0316	1.0280	1.0274	
September	1.0321	1.0279		
Average	1.0319	1.0282	1.0280	1.0280

Arithmetical relationships have been established between the constituents of whey and formulas to represent these relationships have been worked out[1]. In an exhaustive examination of a number of samples of milk and whey Cochran[2] found for whey that if the number representing the specific gravity above 1000 be divided by 4.25 the quotent = total solids.

The minimum and maximum figures along with the corresponding percentages of total solids found in the present experiments are -

	Minimum	Maximum	Average
Specific Gravity	1.0274	1.0286	1.0280
Total Solids %	6.57	7.13	6.85

In whey, variations in milk sugar being the principal constituent, accounts mainly for differences in specific gravity.

Whey Solid is the residue left after the evaporation of water. As already shown it is composed of those constituents, principally sugar and albumen, which are not

(1) Droop-Richmond - Dairy Chemistry 1920 p.76-80.
(2) Milk, skim milk and whey. A study of their composition and Specific gravity. Cochran J. Am.Chem Soc.1893.15.347-351.

retained in the curd formed by the action of rennet upon milk. For this reason it is possible to roughly divide the constituents of milk including those in solution and in colloidal suspension, into cheese solids and whey solids. The division is not strictly accurate since a certain proportion of whey is always left in the curd and vice versa.

The average percentage of total solids in whey obtained at the three centres is as follows:-

Dairy School	6.9
Factory 4.	6.74
" 2.	6.93
Average	6.86

At the Dairy School the whey solids gradually increase with advance in the cheese-making season. While at the two factories, the amount falls off towards the close of the season. (See Table XX. in appendix). The figures are in agreement with the observations made in respect to the variation in milk constituents.

The extreme monthly variations are shown in Table XVII below.

Table XVII.

Total Solids in Whey - Extreme Monthly Variation.

	Total Solids in Whey %.		
	Minimum	Maximum	Average
April	6.84	7.06	6.92
May	6.78	7.13	6.88
June	6.72	6.98	6.85
July	6.79	6.90	6.84
August	6.57	6.90	6.76

The limits of variation are 6.57 and 7.13%; a percentage variation of about 8%.

The proportion of milk solids passing into the whey is shown in Table XVIII below.

Table XVIII.

	Total Solids in milk	Total Solids in whey	Whey Solids % of milk Solids
March	12.11	6.42	53.1
April	12.32	6.34	51.4
May	12.26	6.21	50.7
June	12.57	6.25	50.0
July	12.44	6.26	50.3
August	12.69	6.24	49.2
September	12.38	6.30	50.9
Average	12.43	6.28	50.6

From this table it appears that, on an average, about 51% of the milk solids pass into the whey, the remaining 49% are contained in the cheese. Van Slyke[1] gives a similar set of figures.

Average Composition of Factory Whey.

Seeing that the constituents of whey through different causes are subject to variation an important consideration now is - what is the average composition of factory whey? Definite information upon this point is essential when the question of utilisation is under review. The average composition for the season of whey produced at the three factories is given in Table XIX below. The monthly averages are shown in Tables XX andXXII Appendix.

Table/

(1) Van Slyke & Publow. Science and Practice of Cheese-making 1914. p.202.

TABLE XIX.

Average Composition of Whey in percentages.

	Dairy School	Factory 4.	Factory 2.	Average
Water.............	93.09	93.28	93.07	93.15
Protein...........	0.86	0.86	0.89	0.87
Fat...............	0.26	0.16	0.28	0.23
Milk Sugar........	4.78	4.80	4.76	4.78
Ash...............	0.49	0.52	0.45	0.49
Undetermined......	0.50	0.40	0.55	0.49
Total Solids......	6.91	6.74	6.93	6.86
Specific Gravity..	1.0282	1.0281	1.0281	1.0281
Acidity Total.....	0.18	0.18	0.22	0.19
Acidity[1].........	0.13	0.13	0.17	0.14

(1) after addition of potassium oxalate.

The characteristic feature of the above table is the uniformity in composition of average factory whey. Apart from the variation in the fat which has been referred to page 25. the only other comment which appears to be necessary is the fact that the whey gradually becomes richer as the season advances. For example the total solids Table XIX increases from 12.1 in April to 12.7 in August. For variation in acidity and sugar see remarks page 27 & 32.

Nutritive value of Whey.

As already pointed out the principal outlet for whey in this country at the present time is as pig food. For this reason it is necessary to establish beyond doubt the value of the substance for this or similar purposes. As shown on preceding page 37 over 50% of the milk solids are contained in the whey and they include practically all the sugar and the albumen of the milk, along with a little of the fat and a greater part of the mineral matter. These substances which form the whey solids are almost completely digestible. Moreover the whey protein, namely the albumen and the globulin, appear to be biologically identical with the bodies in the blood[1]. Further as milk contains accessory food substances it is likely that some of these pass into the whey[2].

Reference has already been made to the opinions held by prominent agriculturists in the early part of last century respecting the value of whey for feeding purposes (p.23.) Since then a large number of trials have been made in this and other countries with the object of determining its feeding value. As a result of some of the more extensive of these trials the equivalent of whey in terms of other food for producing live weight increase, was found to be as follows:-

7.4	lbs	whole milk whey	=	1 lb mixed meals	for pigs	3
8.0	"	" " "	=	1 do. do.		4
5.5	"	mixed meal	=	1lb Live weight increase	" "	5
3.25	"	Barley meal	=	do. do.	" "	6
4.2	"	" "	=	1lb Pork	" "	"
4.5	"	"	=	1" Live weight increase	" "	7
12.0	"	whole milk whey	=	1" barley meal		8
55.	"	" " "	=	1" Live weight increase		7
2.	"	" " "	=	1" skim milk		8
4.4	"	skim milk	=	1" meal		9
10.	"	Whey	=	1" "		10

Interpretation of the above data shows that about 50 lbs of whey from whole milk cheese produces 1 lb live weight increase in pigs. The value will alter according to the actual food deficiencies of the rest of the diet, which the whey can supplement. Whey from separated milk cheese requires about 60 lbs to give the same result.

(1) Milk and its hygienic relations. Lane-Claypon J.E.1916 pp.31 & 32.
(2) Note on the Vitamine content of milk. Hopkins Vol.XIV. 1920; An attempt to estimate the Vitamine fraction in milk. Casimir Funk Bio Chem Jour Vol VII 1913 etc.
(3) Bull 225 Ontario Department of Ag. 1914 p.34.
(4) 8th Annual Report Ag.Exp. Station Wisconsin 1882 p.441.
(5) Foods and Feeding. Henry p.574.
(6) Jour Ministry of Agriculture XXVII 4. 1920 p.347.
(7) Bull 57 W.S.Ag.Coll. 1911 p.220 & 270.
(8) Danish Expts. Copenhagen results.
(9) Average for Ontario 3.5. Minnesota 4.6. Utah 4.3. Tennessee 4.7. Wisconsin 4.7.
(10) Dairy Chemistry. Snyder 1911 p.110.

The difference in feeding value between whey from whole milk and from separated milk cheese is due to the absence of fat in the latter. According to Henry[1] the removal of fat from whey for the preparation of whey butter reduced the feeding value by about 25%. Sammis considers that skimming of whey removes only about one tenth of its feeding value[2]. But the reduction will obviously depend upon the initial fat content of the whey.

Fed alone to pigs up to an average of 6 gallons daily per pig an average live weight increase of 1 lb per head per day was obtained[3]. Henry on the other hand found that pigs did not thrive on whey alone[4]. The author's experience is that when fed alone in anything like the quantity stated above it is laxative and liable to cause scouring. Apart from this effect whey is not a well balanced food as shown in the average analysis on page 37. It is poor in protein. In consequence it is best fed along with suitable meals to supply the protein deficiency. In the Kilmarnock experiments Two lbs of meal to 2½ gallons of whey was found to be a suitable proportion for adult animals. Replies received from a circular letter dispatched to cheese farms in the West of Scotland asking for information on this point is summarised below:-

No.of farms	Weight of Pigs Stones	No.of Pigs	Ratio of whey to meal Lbs
2	4	80	14 whey 1 meal
41	5-10	224	7 " 1 "
32	11-15	281	5 " 1 "
11	16-20	268	5.7 " 1 "
86		853	

When made into a mash with whey, chemical changes affecting the digestibility of the meal appear to occur, a point which is under investigation. According to the experience of bacon curers a certain proportion of whey in the diet of a pig improves the quality of the bacon.

That whey possesses a food value over and above that supplied by the protein, fat and carbohydrates was observed

(1) Bull 225 Ontario Dept Ag. 1914 p.34.
(2) Cheese making Sammis 1918 p.29.
(3) Bull 57. U.S.Ag. Coll. 1911 p.268.
(4) 8th Annual Report - Wisconsin Expt Station 1891 p.47.

by Henry in 1891. He states that whey increases the availability of the ration by more than the solids it contains. Further good results were obtained by feeding barley and whey together. While whey is poor in protein, the protein which it contains provides a useful supplement to the protein of barley[1]. It was also found that whey and barley or maize was an excellent food for fattening adult pigs, but as a food for young pigs it was necessary to increase the protein. In a series of experiments by the author[2] carried out with the object of determining the experimental error in pig feeding trials, in which whey was used, the variable and somewhat remarkable increases produced by incrementing the quantity of whey consumed, could not be accounted for by the nutrition values of the known whey solids. Results such as these may be attributed to the protein of the whey supplying a deficiency in the protein metabolism of the rest of the diet such as it appears to do when consumed along with barley; or to the presence of accessory food substances which are otherwise wanting or are below the minimum requirements; or lastly it may be due to some influence of the inorganic constituents of the whey. Experimental work on these lines is in progress.

Golding finds that whey is deficient in Fat soluble A Vitamin. According to McCallum & Davies[3] whey from which albumen has been removed by coagulation can be kept at the boiling point for six hours without any appreciable loss in its nutritive activity in so far as the water soluble accessory food substances are concerned.

Whey is used for infant feeding[4] and for dietetic purposes[5]. It is now on the market in the form of a powder[6] having the following composition.

Moisture	1.20
Fat	0.27
Protein	14.25
Sol.Carbohydrate	74.45
Ash	9.83

(1) Bull 319 Wisconsin Exp. Station 1920 p.71.
(2) Errors in feeding experiments with cross bred pigs. R.A.Berry & D.C.O'Brien. Jour Ag. Sc.Vol.XI. Pt.III. July 1921.
(3) Jour Bio Chem.23, 1915 p.249.
(4) Whey in infant feeding. Bosworth A.M.Am.Jour dis children 9.2.1916. Feeding of children on whey food. Giffhorn H.Jahrb Kinderheilk 77.1914 635-639. Food Products from Whey, Process of producing. Ramage A.S. U.S.Pat.735.148.1903.
(5) Whey utilisation for dietetic purposes. Bond Eng.Pat 23127 Oct 1909.
(6) Casein Ltd. Battersea London.

The condition of the whey whether fresh or stale influences its feeding value (see p. 27). Kellner[1] states that it is advisable to feed whey in a boiled condition and that sour whey is unsuitable for delicate pigs. But using sour and sweet whey respectively in some pig feeding experiments carried out by the Ontario Agricultural College no difference was found. The whey used by the author in pig feeding experiments at Kilmarnock contained from 0.5% to 1.0% of total acidity. The higher figure was obtained in the summer.

Compared with succulent crops for pigs, whey was found to be slightly superior in feeding value to that of turnips[2]. An opposite result to this was however obtained in a number of trials carried out at the Experiment Stations of Ohio, Montana, Utah and Ontario, where an average result of 5.7 lbs roots was found to be equivalent to 1 lb of meal for producing live weight increase and which works out to a ratio of 1.5 lbs whey to 1 lb pulped roots. As would be expected the results obtained at individual stations varied considerably. For calf feeding 1 lb whey was found to be equal to ½ lb of skimmed milk[3] which agrees with the figure for pigs. For cows given at the rate of one gallon per day it exercises a favourable influence on the yield and quality of milk[4]. As poultry food[5]. excellent results have been obtained both for egg laying and for fattening. For feeding bees whey is recommended in the following proportions:

Boiling water	225	grs
Fresh whey	225	"
Cane sugar	400	"
Honey	140	"
Phenix syrup	10	"
	1000	"

<u>Market price</u> of whey varies according to the local demand for pig feeding and to the quantity produced daily. Where the production is greatly in excess of the demand or when it is not consumed at the factory as pig food, it can

(1) Scientific Feeding of Animals. Kellner 1909 p.220.
(2) Report 30 Wisconsin Ag. Expt. Station 1895.
(3) Graef-Milch-Zeitung 1880 p.183.
(4) Schrodt Jahresb J. Ag. Chemie 1882 p.441.
(5) L'Industrie laitiere. Paris, 1910. 47 pp. 757-759.

be obtained for the cost of carting. Replies received from factories in answer to a query asking for the current market price obtainable for whey in 1921 included 0d $\frac{1}{4}$d $\frac{1}{2}$d $\frac{3}{4}$d 1d $1\frac{1}{2}$d per gallon. The pre-war value placed upon whey at the dairy school was $\frac{1}{2}$d per gallon, a figure also quoted in 1916[1]. Van Slyke puts its value at from 8 to 10 cents per 100 lbs for feeding and from 6 to 7 cents for the extraction of sugar.

Manure Value.

The value of whey for manurial purposes is derived from the nitrogenous and inorganic constituents. The former, before assimilation by plants require to undergo change in the soil to the nitrate condition. The latter are already in an assimiable form. The average percentage composition is as follows:

Nitrogen	0.13 %
P2O5	0.12 "
K2O	0.16 "
CaO	0.07 "

The sugar is a source of energy for soil organisms.

As already pointed out on p. 4 a few of the factories in the past year were spraying whey from a water cart on to permanent pasture. The result was favourable but the carting made the cost excessive. In Ireland at least one factory, namely that of the Ardagh Co-operative Society[2] whey is irrigated on to pasture fields from the months of June to September at the rate of 1000 gallons per 2 acres per day, and the pasturage is used for grazing. The practice has been carried on for several years on the same field and the effect appears to be to encourage coarser grasses. Applied at the rate of 2000 gallons daily per acre on another field the pasturage became unfit for grazing. The soil was used as a filter bed. But in this case the whey was first drained through peat to remove suspended solids and the spent peat afterwards used as manure. Whey is boiled to precipitate albumen which is skimmed off and employed for making compost.

(1) Jour Bd.of Ag.& Fisheries Supplement 16. 1916.p.24.
(2) Ninth Annual Report. Royal Commission on Sewage 1915 p.93.

With the object of testing the value of Whey for manurial purposes field and pot experiments were carried out at the Experiment Station Kilmarnock in the summer of 1921.

Pot Experiments. Oats and Rape. Poor sandy soil from Gargerston, Kilmarnock was used. The scheme which is shown below was carried out in duplicate.

Treatment	Weight of Oat Crop dry.
Pot 1. untreated	177.0 grams
2. complete manure	432.5 "
3. whey	291.5 "
4. " neutralised with lime and clear liquid used	325.5 "
5. " carbonate of lime added to soil	360.7 "

The complete manure was applied at the rate per acre of $1\frac{1}{2}$ cwts of nitrate of soda $2\frac{1}{2}$ cwts of superphosphate of lime and $\frac{3}{4}$ cwts of sulphate of Potash. The whey added contained nitrogen equal to that supplied in pot 2. It was added in three applications, an equal volume of water was supplied to the pots receiving no whey. Acidity of whey 0.84, 0.86, 0.96%, nitrogen content of whey 0.13%. Weight of soil in Pot 40 lbs.

The seed was sown on 26th May and the crop cut and weighed on August 6th 1921.

The rape was damaged by wind and rain and the results were unreliable. A photograph was taken of the oat crop No. 1. appendix and from its appearance it confirmed the above figures. Similar experiments with oats and rape were carried out in the field. The crops were unfortunately damaged by wind and rain and the crop was not weighed.

The conclusion arrived at from these experiments is that whey possesses definite manurial properties. Previous neutralisation or by application of suitable quantities of limestone to the soil considerably enhances these properties.

Section III.

U T I L I S A T I O N

There are two principal outlets for whey namely 1. as pig food and 2. for the extraction of milk sugar. A consideration of each of these is now taken up.

Pig Food.

In view of the facts brought to light in the foregoing sections it is evident that the crux of the whey problem in so far as pig feeding is concerned is centred in the question of pig accommodation. Presumably had the erection of piggeries on the scale required been a sound undertaking it would have been carried into effect. A short whey producing season undoubtedly mitigates against feeding upon a large scale. The cost of erection of piggeries however has now fallen from a wartime estimate of from £10 to £12 a pig to between £3 and £4.

Some alternate scheme or modification of the present one is necessary if a solution of the difficulty is to be found. With this object in view the following suggestions are put forward.

1. Farmers supplying milk to the factories to take back on the return journey a proportionate share of whey.

2. Partial or complete drying of part of the whey.

The former plan is carried out with a certain degree of success in other countries. Against the proposal there is the cost and trouble of carting and it would probably mean additional pig accommodation on the farm.

The latter has in it the germ of a complete solution of the problem. The obvious advantages are that dried whey keeps well; it possesses great nutritive value and it is in small bulk. Further it would relieve the congestion of whey at the critical periods. Partial drying up to a concentration of about 70% is less costly. The syrup produced does not keep well but it can be used directly for feeding or for the extraction of milk sugar. There are two processes in use for drying, namely the "roller" and the "spray", each of which the writer has seen an operation. The following is a brief description of each.

The essential equipment of the roller process consists of two horizontal steam heated revolving cylinders or rollers; each about 60" long with a diameter of 28". The rollers are installed sufficiently close to each other so that they are in contact at the peryphery. The liquid distributing tank with adjustable discharge is in the centre over and between the rollers. There are scrapers to remove the dried film and receptacles to catch the powder. The steam pressure inside the roller is sufficient to give a temperature of 124°C. A 4 HP. engine would turn the rollers. Some of the cheese factories have an oil or gas engine and all possess boilers capable of giving a pressure up to 80 lbs per sq.inch[1]. There are at least 7 types of roller plant[2]. details of which are available.

The spray process in the main consists of dessicating the liquid by atomizing in an atmosphere or current of heated air. The small particles of milk spray give up their moisture quickly and drop to the bottom of a drying chamber in the form of a fine powder, while the moisture laden air escapes. The temperature of the chamber varies according to circumstances from 140°F. to 180°F. The process claims not to kill the enzymes nor to destroy the physical condition of the protein. There are many modifications, seven of which the writer has details of. But the process is more elaborate and costly than the roller and for this reason it is not considered necessary to make any further comment.

One pair of rollers will dry up to 1000 gallons of whey daily. But by concentrating the whey first, the drying capacity of the rollers can be trebled. Concentration could be carried out in a vacuum pan or in a single effect evaporator. The latter would dry up to a concentration of between 60 and 80% by weight from 100 to 130 gallons of whey per hour.

Cost of drying is determined on the following basis:

(1) James Milne & Sons Ltd., Edinburgh, Manufacture rollers.
(2) Just. process U.S.A.Pat.712545 Nov.1902 also Just-Hatmaker process; Gathman process U.S.A.Pat.834,516 Oct 1906; Passberg process U.S.A.Pat.726,742 April 1903; Ekinburg process U.S.A.Pat.785,600 March 1905; Gowes process U.S.A. Pat.939,495 Nov.1909; Buflovak process U.S.A.Pat.1916.

Overhead charges

Coal
Labour
Interest on Capital, Depreciation, etc.
Grinding or Kibbling and packing of product.

Coal is the principal item in the cost of production. 1 lb live steam evaporates 1 lb water. 1 lb coal according to its calorific power and to the efficiency of the evaporating plant will evaporate from 5 to 8 lbs of water. Proportion of water in whey 93% and in dried whey 2%.

Capital outlay exclusive of building.

Pair of rollers and accessory parts.
Single effect Evaporator Plant or Vacuum pan.
Oil Engine 4 to 8 HP.
Boiler to give 80 lbs pr. per sq.inch.

A Roller drying plant it is stated would cost between £400 and £500 and a partial drying plant from £700 to £800, in each case exclusive of the building.

Without access to factory records, and with wages and material fluctuating, it is not possible to arrive at a true costings estimate. From information supplied the cost of drying whey by the roller process at the present time is round about 2d per lb or £18:13: 4 per ton.

Average Composition of whey solid is shown below, Table XXII.

Table XXII.

Average Composition of Whey Solid, percentage amounts.

	Dairy School	Factory 4.	Factory 2.	Average
Protein........	12.55	12.86	12.81	12.74
Fat............	3.76	2.37	4.04	3.39
Milk Sugar.....	69.18	71.22	68.69	69.70
Ash............	7.19	7.64	6.54	7.12
Undetermined...	7.32	5.91	7.92	7.05

<u>Other outlets for Whey solids</u> are -

Baking and Confectionery Trades.
Invalid foods, dietetic preparations etc.
Extraction of milk sugar.
Poultry, calf foods, etc.

In bread-making[1] the whey solids add to the neutritive value of the flour and at the same time act as yeast food. In the confectionery trade the solids are used as a constituent of baking powder[2]. The lactic acid of the whey replaces whole or part of the usual acid in baking powder. Use is also made of the solids as constituents of invalid foods[3].

It is difficult to obtain reliable data showing the extent to which whey solid are employed for the purposes mentioned. In all probability the amount is small.

Extraction of Milk Sugar.

Until recent years milk sugar was not manufactured in this Country. Now there are at least three lactose factories in the United Kingdom namely:- The Government factory at Haslington; The Wholesale Co-operative Society's factory, Basford Bridge, both near Crewe; and the lactose factory, Tipperary. The first two have been erected since the war, whilst the latter has been in existence some years. When fully working the production of each factory is estimated at from 100 to 150 tons per annum.

<u>Importations from abroad</u> are given below[4].

(1) Improvement in the manufacture of bread, Tooth Eng. Pat. 6103 1891.
(2) Stillrell U.S. Pat. 26168 1909.
(3) Food Manufacture of Articles of, with the use of sour whey solids. Townsend Eng. Pat. 158684 1919.
(4) The figures were kindly supplied by the Statistical Officer, Customs & Excise London 2/4/21.

	1920		1913
	lbs.	% of Total	% of Total
Netherlands	303,752	33.7	40.2
United States	542,178	60.0	-
Victoria	5,600	0.6	-
Germany	49,280	5.5	44.2
Belgium	-	-	2.4
France	1,648	0.2	10.8
Italy	-	-	2.4
Total	902,458		
Money value	£69,836		
Price p.lb.	18.4d		

Uses of milk sugar, information concerning which has been obtained mainly by correspondence, may be summarised as follows:-

Manufacture of Infant and Invalid foods.
Addition to diluted milk for infant feeding.
Pharmacy, homeopathic medicines etc.
Chocolates.
Milk stout.
Lactic acid.

To consider these in turn. -

Infant and Invalid foods, absorb the bulk of the milk sugar consumed in this Country. Refined or B.P. lactose is mostly employed, though crude lactose containing some albumen and ash is also used in the preparation of nutritive foods. The amount present in proprietary foods varies[1]. The quantity consumed by the larger firms manufacturing these foods will probably range from 20 to 60 tons per annum. The total consumption may reach between 300 and 400 tons per annum.

Pharmacy. Pure or technical lactose is practically restricted in its use to medicines and dietetics. In pharmacy it is largely employed as a dilutent and for the sub-division of drugs such as in the administration of grey powder, calomel etc. Further, in connection with homeopathic

(1) See Food & Principles of Dietetics. R.Hutchison 1918.

medicines it is useful as an absorbent of hygroscopic substances such as plant extracts etc. The actual quantity used in this way is relatively small.

Chocolate. Information obtained from a number of manufacturers goes to show that milk sugar is not atpresent a regular constituent of chocolate. The main reason for this is the fact that it has to compete with cane sugar and being more costly,& not as sweet, it could only partially replace it. However if the price were lower there appears to be considerable scope for its use in the Chocolate industry.

Milk stout contains lactose. Being unfermentable by ordinary brewers yeast, this sugar remains unchanged in the fermented product and to which it communicates a fulness of taste which is not easily obtained in any other way. Crude lactose is employed and its use for this purpose is controlled by patents[1]. At present the amount used is probably about 150 tons per annum.

Lactic acid. The manufacture of this substance provides an insignificant outlet. The acid is only used in quantity by Tanners, Woollen Dyers and Calico printers. Starch[2] from maize, potatoes etc., provides an alternate method for its preparation, so that the price of crude lactose must be such that it can compete with that of fermentable carbohydrates derived from the above sources.

Process of Manufacture.

The manufacture of milk sugar was originally started in Switzerland, but it has now extended to several European Countries, to the United States and to the Colonies. The Swiss and German methods of manufacture represent the two different processes in use at the present time, a brief description of which is given below.

(1) Milk stout makes on Eng. Patents 13528 June 1908. 1269. Jan. 1909.
(2) Manufacture and application of lactic acid. A.A.Claflin. Jour.Soc.Chem.Lnd. 1897 p.516.

Swiss Method consists in concentrating the whey to about 1/3rd of its original volume by boiling in cheese kettles; the albumen which separates out is skimmed off along with the fat. The liquid is further concentrated in vacno at a temperature of 146°F. to a suitable consistency and the product run into large enamel pans with rotatory stirrers where crystallization takes place. The residue is yellowish brown or chocolate in colour and consists of impure sugar called "sugar sand". It is consumed to a small extent of food but its principal outlet is for purification by sugar refiners. The above process is simple but wasteful as during the boiling part of the sugar is converted into a non-crystalline form and at 70°C slight decomposition commences, the rate of which increases as the temperature rises[1].

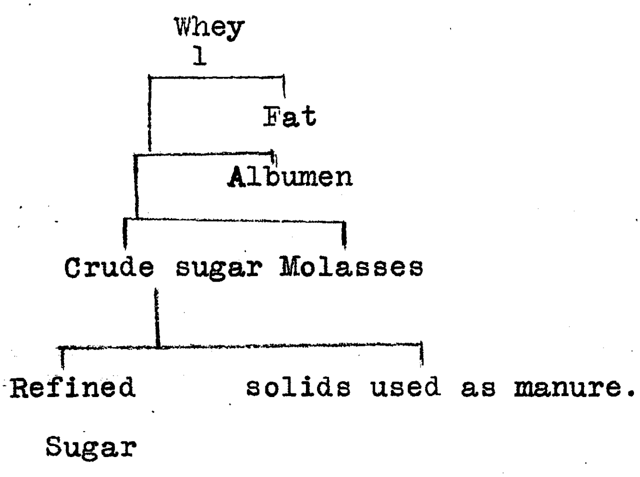
In Scandinavia whey is boiled down in the same way as maple juice, until on cooling it solidifies into a yellow crumbly mass which is used as food under the name of Primost. On adding buttermilk or whole milk to the whey, the product which is pasty, is called Mysost[2].

German method[3]. The whey is neutralised with milk of lime and condensed to about 60% in vacuum pan until the specific gravity reaches 30 to 32 B. The thick syrup is then run into shallow vats and occasionally stirred during the first ten hours. To separate the crystals the sticky mass is mixed with cold water and centrifuged and the lactose crystals obtained are washed on a drum. Two thirds of the milk sugar is extracted in this way, the remainder being left in the syrup. The latter is heated to boiling, the coagulated albumen skimmed off and the liquid again concentrated in vacno to 35°B. After cooling the lactose separates, is washed and the quantity recovered amounts to a percentage of 0.3 to 0.7 of the whey. About 4% raw milk sugar is obtained from whey. The raw milk sugar is refined, for details of method the original papers referred to must be consulted. The refined sugar is equal to from 2.5 to 2.6% in the whey. Various modifications of this process are in use[4].

(1) The Book of the Dairy. W.Fleischman 1896 p.258.
Thorpes Dictionary of Applied Chemistry.
(2) Cheese-making, Decker 1918 p.221.
(3) T.Aufsberg. Chem.Zeit 1910, 34.885; J.Pedersen. Jour. N.Zealand Dept Ag.Chem. & Drug. March 1913.
(4) Mumford U.S.Pat.1,366,822. 1921; Dietrick U.S.Pat. 1,201,027. 196. Martin Eng. Pat. 161887 1921 etc.

In connection with the evaporation of milk and whey and the extraction of sugar, there are a number of important physico-chemical problems awaiting solution. Among them may be mentioned - the escape of gas accompanied by great frothing from colloidal solution; the crystallization of milk sugar in presence of soluble salts and substances which react upon the sugar; the separation of colloidal substances like albumen in a condition for use as human food or dried into a condition for storage either for consumption as cattle food or for industrial purposes.

By-products are formed at different stages in the process of extraction, and a graph to represent which has been drawn up and is shown below -



Cost of Production

As already remarked in the case of whey powder it is inadvisable, without access to actual records of factory working, to attempt to give actual costing figures. But it may be stated that in pre-war days, machinery, exclusive of the building, to handle 4000 gallons of whey daily is stated to cost about £2000, and between the years 1900 and 1910 the cost of production of lactose from whey valued at ½d per gallon varied from £40 to £62 per ton[1]. This does not take into account the value of the by-products of which albumen is the principal. By the Swiss method of extraction £20 per ton for crude lactose has been put as the cost of extraction.

Dempster states that it requires six men and six tons of coal to produce one ton of sugar and that the cost of extraction is 6d per lb.[2] On the other hand the cost of coal per lb of sugar is put at from 3d to 4d to which is added another 5d to cover labour and necessary expenses, making a total of from 8d to 10d per lb.[3] of sugar.

At the present time a complete sugar extraction installation to deal with from 3 to 5,000 gallons of whey daily, exclusive of the building in this Country would cost between nine and ten thousand pounds, the minimum cost of production is put at 1/- per lb. of sugar.

A regular supply of whey amounting on an average to not less than 1000 gallons daily over a period of from 8 to 9 months would of course be necessary, otherwise over-head charges would become excessive and would considerably augment the cost of production. In absence of fresh whey, whey solids could be used as the raw material and the re-fining of the crude lactose would form part of the routine factory work when the cheese-making season is past.

Against the cost of production of milk sugar must be placed the value of the by-products a short description of which is given below.

Whey Cream and Butter. At the factories in Switzerland, Austria, Holland, Bavaria, etc., the practise is to skim the whey, formerly by hand, later by a milk separator and more recently by a whey separator and to churn the cream into butter. Since 1912 most of the American cheese factories have installed whey separators and have found it profitable. The whey should be separated as quickly as possible after it is drawn from the vat. From there

(1) Pedersen. ibid.
(2) Milk Products in Europe & America. N.Dempster Bull.86. New Zealand Dept of Ag. 1920 p.13.
(3) From International Sugar Journal.

it should run by gravitation into the whey tank. As the whey passes from the tank to the centrifugal machine, the small pieces of curd invariably present should be first strained out. The separator should be adjusted so as to produce cream containing from 50 to 75% of fat. The cream which is sometimes pasteurised can be used for making butter or for use in ice-cream etc. When separated by skimming after the whey has been standing in a tank, the cream (owing to certain decomposition changes) is regarded as a half worthless product[1].

The yield will depend upon the percentage of fat in the whey. The average percentage of fat in whey from Cheddar Cheese in these experiments was 0.23, 1000 gallons of whey would yield 27 lbs of whey butter. Whey butter is softer and is reputed not to keep as well as milk butter. The price per lb. of this butter manufactured in this Country is put at from 9d to 10d per lb.[2]

The question of making whey butter is largely a matter of cost of production. According to Van Slyke it would not be profitable to remove the fat unless the daily yield was 1000 gallons of whey containing 0.25% fat[3]. The initial cost is the installation of a separator. A centrifugal separator to deal with 500 gallons of whey per hour would cost under £200[4]. Guthrie gives a detailed cost of production[5]. In the United States "whey butter" must be sold and labelled as such[6].

By skimming off the fat the nutritive value of the whey for pig feeding is diminished. For this reason it is necessary to decide whether it is more profitable to sell fat in whey cream or feed it to pigs. Relative market values will determine this point.

<u>Whey albumen</u> is a particularly valuable substance and its separation in a form so that it could be marketed either alone or in an admixture is a matter which as yet

(1) Milk Cheese & Butter. Oliver, London 1891 p.81.
(2) Supplement No.16. Jour.Bd. of Ag. Sep 1916 p.24.
(3) Science & Practice of Cheese-making - Van Slyke & Publow 1914. p.65.
(4) Watson Laidlaw & Co. Ltd., Dundas Street, Glasgow.
(5) The Book of Butter. Guthrie. Chap.XIII;
(6) The Butter Industry, Hunziker 1920. p.581.

is hardly beyond the experimental stage. In Austria, Switzerland, France etc., the albumen which separates on heating whey is made into Ziger[1] Ricotta or Ricorta[2] cheese. Molasses and Manure are other by-products.

Until the forementioned products become established articles of trade in this Country their Commercial value remains uncertain. Nevertheless, they form an essential part of any scheme for utilising whey.

Miscellaneous uses of Whey

Owing to the space which it would occupy, it is not considered necessary to give details of the minor uses to which whey is put. But the following list with references is given -

Vinegar from Whey[3] Manufacture of Alcohol[4] An antimony mordaunt from whey[5] Whey Lemonade[6] Malted whey[7] used in the manufacture of bread, cakes, biscuits etc.

Summary of Results and Recommendations.

1. The yield of whey from the manufacture of cheese in Scotland in 1920 amounted to between 17,000,000 and 18,000,000 gallons which is equivalent to over 10% of the milk production of the Country. About one half is produced at the farm and the remainder at milk factories.

Of the former the average daily production per farm was about 112 gallons with a minimum of 12 and a maximum of over 300. The corresponding figures for the season being

(1) Book of Dairy - Fleischman 1896. p.268.
(2) Cheese making - Dicker-Sammis, 1918. p.219.
(3) Process of obtaining table liquor. Lamsuroux p. Paris Eng.Pot.5562 1909; Kokosingki M.Mond.Prod.Chem.12.194.
(4) Whey & skim milk for diluting molasses, use of. Von Bohle Cent. Zuckerind 15.68.70.
(5) Kritschmar M. Chem. Zeit. 12-943.
(6) Burri R. Die Molken lemonade - Molkerei-Zeitung 5.81.1913.
(7) Stillwell J.S. U.S.Pat.1,041,896. 1912.

26,000 with a minimum of 600 and a maximum of 84,000. The cheese-making season lasts on an average 227 days, the shortest being 60 and the longest over 300 days.

Of the milk factories which number approximately 50 it is of interest to record that one half are owned by Co-operative Dairy Farmers Associations and that most of them are affiliated with the Scottish Agricultural Organisation Society. The milk handled by these centres amounted to almost 20% of the total production for Scotland. Nearly 75% of the factories make cheese. The average consumption of milk for cheese-making is about 41% of the annual turnover, the minimum being 2% and the maximum 90%. The average daily yield of whey per factory varied from 100 gallons to over 3000. For the season the average yield was 233,000 with a minimum of 8000 and a maximum of 554,000. The factory cheese-making season lasts on an average 165 days with a minimum of 130 and a maximum of 214.

The above figures are directly applicable to the year 1920 only, but they provide a useful index to those for other years.

2. With regard to waste. On the farm provision is generally made on a sufficient scale for the consumption of all the whey by pig feeding. Owing, of late years, to a scarcity of home-bred and imported pigs, there have been unavoidable losses.

At the factory several thousands instead of hundreds of gallons require to be disposed of daily. A few factories continue to run the whole of it to waste, but most of them have attempted to deal with it as pig food. However, in many cases, the pig accommodation provided is not sufficient to allow for a consumption during certain months of the year of much more than one half of the daily production. The remainder is either discharged into streams or at considerable expense sprayed on to the land as manure.

3. As a result of the milk analysis unexpected differences were found in the composition of factory milk used for cheese-making. The difference is shown in the following average figures:

	No.1.	No.2.
Water..............	87.57 %	87.97 %
Protein............	3.21 "	3.08 "
Fat................	3.55 "	3.12 "
Milk sugar.........	4.80 "	4.79 "
Ash................	0.71 "	0.72 "
Undetermined & Loss	0.16 "	0.32 "
Total solids.......	12.43 "	12.03 "
Specific Gravity...	1.0320	1.0323

An explanation of the difference was found in the fact that milk No.1 was mixed morning and evening and milk No.2 was morning only. The solids in the former gradually increased with advance of the season, whilst in the latter they remained stationary. The average proportion of Casein in milk was 3.06% and of albumen 0.51%.

The mean of a number of analyses of the ash of factory milk was as follows:-

	Milk	Ash
CaO	0.167 %	22.8 %
P_2O_5	0.219 "	30.1 "
MgO	0.021 "	2.9 "
K_2O	0.177 "	25.7 "

The above proportions were found to be subject to variation according to season and stage of lactation.

4. The average composition of factory whey was found to be as follows:-

Water...........	93.14 %
Albumen.........	0.56 "
Caseose nitrogen	0.31 "
Milk sugar......	4.78 "
Fat.............	0.23 "
Ash.............	0.52 "
Undetermined and Loss.........	0.46 "
Total Solids	6.86 "
Specific Gravity	1.0281

In connection with whey the first point to draw attention to is the closeness in the average composition of whey produced at different factories. It must not be assumed from this statement, however, that whey is a product of constant composition. The kind of variation met with can be gathered from some figures obtained in the present research, which are given below.

	Maximum	Minimum
	%	%
Water.............	93.43	92.87
Protein...........	0.95	0.82
Fat...............	0.36	0.12
Milk sugar........	4.88	4.53
Ash...............	0.65	0.37
Total Solids......	7.13	6.57
Specific Gravity..	1.0286	1.0274

Although whey is a by-product of milk and its chemical content is primarily determined by that of milk, the principal cause of variation is due to different or defective methods of cheese-making. In the course of this investigation it was made clear that the fat content was independent of that in milk. In respect to milk sugar bacterial activity was the deciding factor. Whey, stored in bulk for 80 days and tested weekly, showed a decrease of milk sugar from 4.9% to 2.8%. In the case of proteins, the albumen of milk passing into whey, except under defective methods of cheese-making, remains much in the same proportion. But the amount of caseose nitrogen varies with the extent of enzyme action. As an example of the latter, reference need only be made to the change in the protein content of whey produced at different stages of cheese-making when the action of rennet enzymes play a definite part. Acidity being essentially a bacterial product of sugar, up to a certain limit varies inversely with the latter. Likewise increased concentration of acid in milk brings into solution a portion of the insoluble mineral constituents.

Apart from the above reasons there was a gradual increase in the solids in whey corresponding with those in milk, as the season advanced. This was also reflected by an increase in the specific gravity figures obtained at one of the factories.

Variation in the ash was considerable, a result which is probably slightly magnified owing to a difficulty in determining the ash by the direct ignition method adopted in the early part of the investigation. Partial analyses of the ash were made with the following average results:

	Whey	Ash
	%	%
CaO	0.066	12.5
P2O5	0.119	22.4
MgO	0.017	3.3
K2O	0.163	28.3

Lime and phosphoric both increased in the whey as the season advanced. The mineral constituents are present mostly in combination with lactic, phosphoric, and hydrochloric acids.

5. The average proportion of milk constituents passing into the whey found in this investigation is shown below.

Water	95.0 %
Ash	70.0 "
Sugar	93.5 "
Protein	25.5 "
Fat	6.5 "
Solids	50.6 "
CaO	36.0 "
P2O5	49.0 "
MgO	75.0 "
K2O	80.1 "

6. In respect to the general properties of whey. On standing, a thin layer of fat separates almost at once and a slight sediment of curd deposits. Within twenty four hours the sugar content falls and the acidity rises each by nearly one half per cent. The acid precipitates the albumen and the liquid soon becomes very turbid and lumpy and a thick scum forms. Moulds and other organisms make their appearance and for the next fourteen days or so as judged by the sugar content little further change appears to occur. After that it is evident that a complicated

series of fermentation changes are in operation. There is a brisk evolution of carbon dioxide and the percentage of sugar falls at the rate of 0.2 to 0.3% per week, until within 80 days a drop in the percentage of sugar from 4.9 to 2.8% was registered. In the same period the acidity expressed in terms of lactic acid increased from 0.14 to 0.64%. The average temperature was 54°F. Experiments on the effect of different temperatures, pasteurisation of whey on changes during storage of whey are in progress.

7. The nutritive value of whey as expressed in terms of (1) number of food nutrients or (2) its power of producing live weight increase as determined by results of feeding experiments, is as follows. In respect to 1, the percentages of nutrients are -

Albumen	0.56
Casein nitrogen	0.31
Milk sugar	4.78
Fat	0.23

Assuming they are completely digestible, the starch equivalent G D E per 100 lbs is 6.4; Availability 100; Nutrient ratio 1:6.1.

In respect to 2. 50 lbs (5 gallons approximately) of whey on an average produce 1 lb. live weight increase (pigs) which is equal to 0.75 lb. dressed carcase. For dressed carcase the current market price is 126/- per cwt, equal to 1/1 per lb. Therefore on the above basis the return in dead meat fixes the value of whey at 2d per gallon consumed.

Calculated on the whey solids the value works out as follows. - Whey contains 6.86% of solids, 50 lbs whey will therefore contain 3.4 lbs solid, its equivalent in dressed meat is 0.75 lbs. Therefore dressed meat at 1/1 per lb. fixes the value of whey solids at from 2d to 3d per lb. consumed.

As to the presence of accessory food substances, there is direct evidence to show that whey possesses a food value over and above that supplied by the protein fat and carbohydrate which it contains. This is a fact of considerable practical importance. Further elucidation of this property by feeding trials with pigs is urgently needed. It is stated that whey is lacking in vitamin A. a deficiency which can easily be made good.

Fed in moderate quantities and supplemented with suitable meals, whey has proved itself an excellent food both for growing and fattening pigs. Moreover it is the opinion of bacon curers that whey improves the quality of bacon.

Attention however must be directed to the fact that the nutritive value of whey diminishes with storage. It should be utilised the day of its production. The whey tank should be emptied daily and occasionally thoroughly cleaned.

8. Manure value per ton of whey based upon the amounts of nitrogen phosphoric acid and Potash works out as follows -

				s.	d.
Nitrogen 0.13%	at 20/-	per unit of	nitrogen	1	3
Potash K20 0.16%	4/6	" "	Potash	-	6
Phosphoric acid 0.12% equal to					
Phosphate of lime 0.26%	at 2/10	" "	Phosphate	-	9
				2	6

Used in pot experiments with Oats in quantity to supply nitrogen equal to that contained in a dressing of 1 cwt of nitrate of soda per acre, a yield considerably above that from the control pots was obtained. It was further increased by neutralising the whey with lime.

Manurial value per ton of consumed whey works out as follows -

Nitrogen	6½d
Potash	6d
Phosphate	6d
	1/6 per ton

9. Considering now the question of utilisation, the conclusion arrived at as a result of this investigation is that pig feeding must provide the main outlet for whey. In coming to this decision account was taken of the following facts (1) A considerable amount of capital has already been expended in the erection of piggeries, the cost of which has now fallen from a wartime estimate of between £10 to £12 a pig to between £4 and £5 a pig. (2) Importations of ham and bacon into the United Kingdom in 1919

amounted to a value of £90,000,000. (3) Whey is a cheap and excellent pig food. The return in meat for whey consumed is equal to a value at present dressed carcase prices of 2d per gallon exclusive of manure value. Eight million gallons is the estimated annual production of factory whey in Scotland which at 2d per gallon works out at a value of over £66,600. (4) In the past factory authorities have been somewhat indifferent to the potential value of whey. Realising its true value there may now be less reluctance in making adequate provision for its utilisation. Apart from the conversion of whey into valuable human food the trouble which it creates by discharging it into streams would be abolished. Pig manure can be readily disposed of and is a source of profit.

A short whey producing season undoubtedly mitigates against pig feeding on a large scale. To adjust this difficulty it is proposed that part of the whey be dried and used as pig food or for any other purpose. Complete drying over steam heated rollers at current values of coal and overhead charges is round about 2d per lb of dried whey. No special training is required to work the drying plant. Partial drying up to a concentration of 70% would cost less. Now 3.4 lbs whey solids produce 1 lb Live weight increase, which as already explained works out at a value of between 2d and 3d per lb. of dried whey.

Just as it is uneconomic to equip milk factories where cheese production is on a small scale and for short periods with a complete cheese-making plant, so it would be unsound to install a drying plant at all factories. The suggestion is made that in Ayrshire for example where there are eight factories, each affiliated with the Scottish Agricultural Organisation Society, and within a radius of 10 miles, there should be co-operation in the sense that cheese-making should be restricted to certain factories only. It would mean an efficient organisation for allocation of milk.

Dried whey is a valuable food for poultry, calves, in fact all stock. Other outlets for it are in bread-making, nutritive foods for the extraction of milk sugar etc.

10. The alternative to pig feeding is the extraction of milk sugar and other substances. In approaching this matter there are several leading facts to be considered. (1) The

annual consumption of milk sugar in Great Britain is probably between 500 and 700 tons, most of which at present comes from abroad. Before the war there is ample evidence of over production and that the substance was a "drug" on the market. There are over 350 milk factories in Great Britain. (2) The cost of extraction of milk sugar at the present time is estimated at 1/- per lb. The outlets at its present market price are restricted. Its principal competitor is cane sugar which is sweeter and is sold at a lower price. (3) Countries where the extraction of milk sugar is an old established industry have the initial advantage of factories equipped for this purpose. Further a sugar extraction plant is often associated with a milk products factory which provides an outlet for sugar in the form of proprietary foods. (4) The yield of milk sugar is estimated to be equivalent to a 2.5% in whey. The value of the by-products are not sufficient to compensate for the high cost of sugar extraction.

Comparing further the two outlets for whey (1) as pig food and (2) for the extraction of sugar. In the former capital outlay is confined mainly to the erection of piggeries to which may be added a drying plant; the latter involves the erection of a special building, installation of an expensive plant, and a technically trained staff.

Recommendations.

1. That pig feeding at milk factories be extended so as to deal effectively with all the whey produced.

2. That cheese-making be restricted to factories where reasonable quantities of cheese are made and the season is of reasonable length and that arrangements with this end in view be made between affiliated Associations of Dairy farmers.

3. Where necessary a plant for drying whey be installed.

4. The erection of a drying plant at a suitable centre for the purpose of providing material for research connected with the value of dried whey and dried separated milk for pig feeding and other uses.

5. The establishment of a factory in Scotland for the manufacture of milk products other than cheese.

B. MANURIAL PROPERTIES OF LEAD NITRATE.

Introduction

This investigation was undertaken in response to enquiries respecting the use of lead nitrate as a source of nitrogen for manurial purposes. Nitrates constitute one of the principal fertilising materials and to the agriculturist any addition to his choice of selection of this particular form of combined nitrogen is a matter of importance.

The ordinary commercial out-lets for lead nitrate at the present time are in the manufacture of paper, printing ink and paint also in calico printing where it is employed as a mordaunt. In the early stages of the War it was used as a shell filling compound. Scrap lead is generally employed for its manufacture a process which is protected by several patents[1]. The trade in this commodity is relatively small. In the Spring of 1922 the cost per ton was about £45. The pure salt contains 8.46% nitrogen.

The action of lead nitrate upon plant growth is complicated by the fact that 1. the salt supplies nitrogen in an available form. 2. Its fertilising properties may be completely destroyed by the toxicity of the lead, and 3. Interaction between the salt and soil constituents. With the object of elucidating some of these points, water culture, pot and field experiments were undertaken.

Water culture Experiments

Oats var. Potato.

(1) Lead nitrate manufacture of - W.Mills. Eng. Pat. 6143 1904. U.S. Pat. 779,092. 1905.

These were carried out with the object of determining the toxic and stimulating limits of lead nitrate in solution. Stimulation was measured by the increase produced in the total weight of plant. In certain cases the weight and length of root and stem were recorded separately. The death point was taken as being the stage when the plant flagged and turned yellow.

To eliminate as far as possible errors due to parental differences in individual grains, "singles" were separated from a number of inflorescenses. The grains varied in weight from 0.04 to 0.045 grams. Germination was produced in sawdust and when the blade was 3" long the complete plant was lifted and transferred to the solution under experiment. The average weight of plant at this stage was 0.127 grams. The plants were held in position by placing through a hole in the cork plugged with cotton wool, inserted into the neck of a bottle; the roots being immersed in the solution. Brown paper was wrapped round each bottle. Corks and other utensils were sterilised in boiling water. In the making of the distilled water a tin condensing worm was employed. It was not practicable to use a distilling apparatus wholly of glass and a silver or platinum apparatus was not available.

The average result of three separate experiments is given below -

Concentration	Lead nitrate	Lead chloride	
	Average Weight of Plant (Grams)		
1: 78	0.126	-	
1: 156	0.138	0.126	Saturated
1: 312	0.153	0.145	solution.
1: 625	0.156	0.144	
1:1250	0.153	0.149	
1: 2500	0.156	0.147	
1: 5000	0.161	0.154	
1:10,000	0.165	0.160	
1:20,000	0.182	0.159	
1:40,000	0.209	0.170	
1:80,000	0.221	0.170	
1:160,000	0.203	0.184	
1:312,000	0.201	0.209	
1:640,000	0.202	0.207	
Control	0.204	0.195	

The above figures are shown graphically in Fig: I. appendix p. 88.

Taking the control as representative of normal growth, it is evident from the curve, fig. I. that concentrations of the nitrate between 1: 40,000 and 1: 640,000 caused stimulation, the maximum effect being produced at a concentration of 1: 80,000. Below 1: 40,000 retardation occurs progressively with increase in concentration. Death occurred within eight days in all concentrations up to 1: 20,000. With the chloride no stimulation occurred until a dilution of 1: 320,000 was reached. Toxicity was more pronounced with the chloride than with the nitrate.

Soil Culture Experiments.

A preliminary experiment was first carried out with Oats and Italian rye grass, with the object of comparing the effect of nitrate of lead and nitrate of sodium containing equal weights of nitrogen. An equal number of seeds were sown in pots each holding 40 lbs soil (Holmes farm) to which was added a manurial dressing of super phosphate of lime and muriate of potash. A solution of nitrate of soda containing 9.96 grams dissolved in 500 cc of water and a solution containing the equivalent in lead nitrate was added to the respective pots in quantities of 125 cc's at a time. The control pots received an equal volume of water only.

Growth in the pots receiving nitrates was much stronger and the foliage was greener than in the control. Where lead nitrate was added it was noticed that the plants possessed slightly broader leaf blades, and the colour of the foliage was of a darker shade compared with that of plants to which nitrate of soda was applied. The lead nitrate solution was three times the concentration of the strongest solution used in the water culture experiments. The ratio of salt to soil was 1: 1125. The result showed quite clearly that soil completely destroys the toxicity of highly concentrated solutions of lead salts such as the nitrate and chloride.

As a result of the preliminary trial other two series of pot experiments were carried out. Light sandy soil from Gargeston was used in series 1. and soil from Holmes farm in series II.

Series 1 consisted of three pots each in triplicate as follows:-

Pot 1. Untreated.
" 2. Nitrate of Soda.
" 3. " of Lead.

The pots were sown with rape, a quick growing plant. The weight of nitrate employed was the same as that used in the preliminary trial. One half was sown at seeding and the remainder top dressed. The effect on the plant of the lead salt was again visible in the darker colour of the leaf and a crop was produced which appeared to be equal in growth to that produced by nitrate of soda. Owing to damage by a storm of wind and rain the plants were not weighed but a photograph had previously been taken, See No. II.appendix .

Series II. consisted of five pots in duplicate. Each pot was sown with Oats (var. Potato) and dressed with superphosphate of lime and chloride of Potash. The nitrate was applied in equivalent quantities, likewise that of the lead. The same number of plants were grown in each pot. Date of sowing May 30th, and of cutting September 14th 1921.

The scheme of manuring and weight of total crop (dry) are given below. -

Pot 1.	No nitrogen	250.0 grams
" 2.	Nitrate of Soda	309.1 "
" 3.	" " Lead	293.7 "
" 4.	Acetate " "	245.1 "
" 5.	" " " + Same as 2	312.0 "

A photograph No.III of the growing plants is given in the appendix.

An inspection of the above figures and from the appearance of the plants as shown in the photograph it is evident that lead nitrate can be used with advantage as a substitute for nitrogenous manures such as nitrate of soda. Acetate of lead used alone in the quantity employed had a slight toxic effect.

Lead poisoning of both crops and stock are known to occur in the neighbourhood of lead mines, the toxic compound generally being galena. Pbs.

Griffith[1] found that the addition of galena to a fertile soil in quantities amounting to 0.4% of the total weight of soil only lowered the fertility to a comparatively slight extent.

The next point to determine was the toxic and stimulating limits of lead nitrate in presence of soil. For this purpose further pot experiments with Oats, were carried out in the Autumn of 1921. Two series were started in the month of October, the pots being kept under glass. Gargeston soil was again used in each case.

Series I. Each pot received in addition to nitrate, a dressing of superphosphate of lime and muriate of potash.

Series II. differed from the former in that chloride in place of nitrate of lead was used; equal weights of lead being applied. In other respects the Pots (2 to 5) received the same dressing as the control. The salts were mixed with soil before sowing the seed.

The treatment and average results obtained are shown in Table XXIII below. Duration of Experiment 73 days.

Table XXIII.

Pot	Lead nitrate added. Percentage of soil			Lead Nitrate Weight of Plant Grams		Lead Chloride Weight of Plant Grams	
Control				Total	Stem	Total	Stem
1	Sod.	Nitrate	0.044%	2.800	2.164	2.897	2.452
2	(Sod.	"	0.022"				
	(Lead	"	0.045"	2.953	2.245	3.394	2.562
3	"	"	0.09 "	2.495	1.836	2.941	2.190
4	"	"	0.17 "	2.512	1.730	2.817	1.874
5	"	"	0.34 "	2.280	1.612	1.464	0.762

The following conclusions are drawn from the above figures.

(1) Griffith J.J. Influence on mines upon land and live stock in Cardiganshire. Jour Ag.Sc.Vol.IX Pt.4 1919 p.388. see also Plumbism or lead poisoning by E.Morgan. Jour Un.College of N.Wales Ag.Dept. Vol.VIII. 1915 p.29-41.

1. Lead nitrate is slightly superior as a nitrogen fertiliser to that of nitrate of soda; the superiority being due to the stimulating action of the lead.

2. Applied in amounts equal to 0.09% of the weight of soil lead nitrate is slightly toxic. At a concentration of 0.34% serious harm to the crop was visible.

Voelcker[1] found that the addition of lead salts up to 0.1% of the weight of soil caused no decrease in the total yield of crop.

Field Experiments

Small plots of 1/200 of an acre were laid out in the Horticultural section (Holmes Farm) in the Spring of 1921 and sown with Oats, var. Potato. The scheme of manuring is shown below. Nitrate of Soda was applied at the rate of 1 cwt per acre and the lead salts containing the equivalent in nitrogen at the same rate. The salts were finely ground and mixed with sand so as to ensure uniform distribution on soil. The seed was sown on the 28th April. One half the nitrate was applied on May 24th and the remainder on June 5th.

Plan

No manure	lead nitrate	Sodium nitrate
Sodium nitrate	No manure	lead nitrate

The plants growing on the lead nitrate plots again showed greater leaf development and were a shade darker green in colour compared with the plants in the nitrate of soda plots. The average size of grain and the date of ripening were practically alike for the manured plots. Owing to losses of grain from attacks of birds it was of no advantage to weigh the produce, but samples of both

(1) Voelcker J.A. Pot culture experiments. Woburn Expt. Station 1915 p.30.

grain and straw were kept to test for the presence of lead. These plots are to remain down for a number of years, the treatment being the same each year; the produce to be weighed and analysed.

No trace of lead could be found in the produce from the plots treated with the lead salt. Griffith found that oats growing on soil contaminated with lead (0.41%) yielded an ash containing 0.07% of lead. The concentration of lead in the present case however would only be about 1 in 10,000.

Reaction between Soil and Soluble lead Salts.

It is quite clear as a result of the foregoing experiments that soil reduces the toxicity of lead salts in solution. The reduction is so pronounced that a concentration in water poisonous to plants, produced in presence of soil a marked stimulation. The cause of the reduction in toxicity would appear to be due to the removal of the greater part of the lead from the sphere of action. Retention in a more or less insoluble condition of the basic radicle of many soluble salts is one of the characteristic features of soil properties. Interchange of bases between soil constituents and salt or adsorption by colloid complexes in soil largely account for the phenomena of retention. In the present case insoluble sulphate and carbonate of lead would probably be formed. It is also a well established fact that the toxicity of single salts is modified by the presence of other salts in solution. Jensen[1] found that quartz alone reduced the toxic effect of poisonous salts particularly in dilute solution.

In 1921 some experiments with soil and aqueous solutions of lead salts were started, an account of which is given below.

100 grams of soil were shaken up with a solution of lead nitrate 1:10,000 and after standing with occasional shaking for 24 hours, the liquid was poured off, filtered and tested for lead. No trace could be found.

(1) Jensen G. Botanical Gazette Vol. XLIII. 1907 p.44.

In another case soil to a depth of $8\frac{1}{2}$ inches was placed in two inverted Winchester bottles with the base cut off. In No.1 water and in No.2 the strongest nitrate solution used in exp. p.65 was drained through and the drainage tested for lead. Reactions for nitrates were of course obtained in both cases but no trace of lead by colorimetric tests could be obtained. Except in No.2 after successive quantities of the lead solution had been filtered through.

Retention of lead varies according to the ratio of the reacting mediums, as shown in the results of the following experiment. The same initial concentration and volume of lead salts was used, but increasing quantities of soil. Oat plants were grown in the liquid after it had remained in contact with soil for 24 hours, poured off and filtered. The plants were weighed and the average figure is given below. In the Control water and soil were used. Experiment started 5th April and was completed 26th April 1922.

No.	Soil -: $Pb(NO_3)_2$	Average Weight of Complete Plants grams.
1	1 : 0.064	0.304
2	1 : 0.032	0.422
3	1 : 0.016	0.633
4	1 : 0.008	0.943
5	1 : 0.004	1.094
6	Control	1.337

Solutions Nos.1 to 3 were poisonous. No.4 slightly toxic. No.5 plant quite healthy.

Colorimetric tests for lead showed that the amount left in solution decreased as the proportion of soil increased. No.5 still gave a test for lead.

The soil left in the Winchesters (experiment page 70) after standing for some time, it was noticed that in the case of No.1 it had a rather unpleasant odour, whilst No.2 had not. To account for this it was thought that the presence of the lead might have altered the bacterial flora of the soil. To test this point the rate of nitrification was used as an indicator.

Lead salt and nitrate production in soil.

Three large Buckner funnels each holding 7 lbs of soil were fixed into a box, sunk into the soil and left exposed several months in the summer of 1921. No.1 had sodium nitrate, No.2 lead nitrate in the same proportion as used in pot experiment p.66. mixed with the soil, No.3 soil alone. The drainage water was collected, evaporated and tested for nitrate by colorimetric tests. The tests showed definitely that the drainage water from the soil to which was added lead nitrate contained more nitrate than the drainage water from the soil to which nitrate of soda was applied. Further tests on these lines are being carried out. An aliquot portion was evaporated to dryness, ignited and weighed; the weights being -

	Total solids grams	Ash grams
No.1	0.847	0.492
2	1.000	0.492
3	0.51	0.327

Hidrion concentration is also being determined in soil media where lead salts exert a stimulating effect upon plant growth.

Conclusions.

Lead nitrate applied in quantities equivalent to those employed in agricultural practice, is superior as a source of nitrogen for fertilising purposes to the usual inorganic nitrogenous manures. Its effect on the plant was to produce a slightly broader leaf blade and a deeper shade of green compared with the effect produced by nitrate of soda. No difference in root development was observed.

Used in the amounts referred to, no trace of lead could be found in the plant, neither could any lead be detected in a solution made by extracting the treated soil with water.

Toxic and stimulating limits of lead nitrate and lead chloride were determined in water and in soil cultures. Except in solution of fairly high concentration soil adsorbs the lead and completely destroys the toxicity of lead salts.

There was evidence to show that the addition of lead salts increased the rate of nitrification in soils.

Lead nitrate contains 8.46% of nitrogen compared with 15.5% in commercial nitrate of soda. The cost of the former at the present time is £45 and the latter £15:10/- a ton.

C. EFFECT OF FREQUENT CHANGES OF DIET ON THE SECRETION AND COMPOSITION OF COW'S MILK.

This investigation is a continuation of a research on problems connected with the feeding of dairy cows and milk production, which has been in progress for several years at the Experiment Station of the West of Scotland Agricultural College Kilmarnock. In a paper[1] already published by the author it was shown that milk yield could be perceptibly increased by feeding the concentrated food in the form of wet mashes. The increase commenced with the advent of the wet feeding and vice versa.

Changes in the dietary of a cow as in the above instance are invariably reflected in the rate of milk secretion and it seemed to the writer that this property might with advantage be put to the test as a means for bringing about increased stimulation of the mammary gland. The cause of stimulation being an issue with which this experiment was not immediately concerned. The present contribution was therefore confined to a study of the point in question.

Method of Experiment

Eight cows in good condition, calving within 42 days of each other, were available at the Experiment Station, Kilmarnock, at the end of December 1920. After a preliminary experiment lasting 14 days they were grouped according to milk yield, period of lactation, date of

(1) Wet and Dry feeding of Concentrates to Dairy Cows. R.A.Berry, Jour. Ag. Sciences. Vol.XI.Pt.1. 1921.

service etc., into two lots of four. Group 1 was fed on a ration which was changed every fortnight; and Group II on a stationary ration.

Water was given twice daily and its temperature and quantity consumed by individual cows recorded. The milk of each cow was weighed morning and evening and the milk fat determined in each. The total solids were estimated twice weekly in composite samples of milk from each group. The temperature of the byre was recorded by a thermograph. Rainfall, Humidity (wet and dry bulb thermometer) temperature of outside air (maximum and minimum thermometers) were taken daily throughout the experiment. Other circumstances which might influence the result, such as indisposition, loss of appetite of the cows etc. were also recorded. A daily chart was kept showing the milk yields, percentages of butter fat, water consumption, air temperature and humidity. Duration of Experiment 16 weeks.

Daily ration per cow.

Common to both lots.

Turnips......	20	lbs.
Hay..........	10	"
Oat-straw....	10	"
Bran.........	1	"
Dried grains.	1	"
Oat grain....	2	"

Group 1. changing diet.		Group II. Stationary diet.
A. Mixture	B. Mixture	
Bean meal....4 lbs	Fish meal 2.5lbs	One half the quantity of mixtures A. and B.
Dec. Cotton Cake......2.5 "	Oat grain 4.0 "	

The above rations each supplied approximately in lbs; Dry matter 28.4, Digestable protein 2.8, Oil 0.7, Carbohydrates and Fibre 12.6.

The meal for each cow was scalded at 3 p.m. at the rate of one half gallon of boiling water to 11 lbs of meal. In the following morning one half of the daily allowance was warmed to body temperature by adding $\frac{1}{4}$ gallon of hot water and fed to the animal and in the afternoon the remainder of the meal was warmed and fed in the same way. Salt was added to each ration except when fish meal was present.

To equalise the effect of advancing lactation and of climatic conditions, two cows of Group I. were commenced on A. mixture and two on B. mixture. The mixture being changed alternately each fortnight.

Daily programme

5 a.m.	Milking	
6 "	$\frac{1}{2}$ daily allowance of meals.	
	Oat straw	5 lbs.
8.15 a.m.	Turnips	10 lbs.
10-10.30 "	Cows exercised and watered.	
11 "	Hay	10 lbs.
3 p.m.	Turnips	10 lbs and cows watered.
4 "	Milking.	
5 "	Remainder of Meals and straw.	

Result of 1921 Experiment

Milk Yield.

The average daily yield in lbs. of milk per week for the two groups is shown in Fig. II. Appendix.

According to this graph the effect on the milk yield of frequent changes of diet compared with that of a stationary diet was to maintain an increased flow of milk. The average daily yield of milk per cow for the former was 26.8 lbs. and for the latter 24.7 lbs. The result is of a practical and scientific interest inasmuch as it establishes the fact that frequent changes of diet, while preserving the balance of supply of fats, carbohydrates and proteins, stimulates the process of milk secretion.

Condition of Animal.

Weight was taken as a measure of condition. Individual cows were weighed each fortnight and to eliminate errors in weighing, check weighings the following morning were made. The average fortnightly weights of the cows in the two groups are shown below.

Weight of Animals - Average of 4.

	Group 1.	Group 11.
1st 14 days	10.2 cwts	9.8 cwts
2nd "	10.1 "	9.8 "
3rd "	10.0 "	9.9 "
4th "	9.9 "	9.9 "
5th "	9.7 "	9.8 "
6th "	9.4 "	9.8 "
7th "	9.2 "	9.9 "
8th "	8.9 "	10.0 "

The cows receiving the changing diet lost weight continuously throughout the whole period of feeding; yet at the termination of the experiment they were considered to be in good milking condition. The gain in milk yield was partly or wholly produced at the expense of body tissue. The cows on the fixed diet maintained their weight throughout. The result is a curious one in view of the fact that the difference between the two methods of feeding did not affect the balance of food nutrients as judged by the ordinary methods of valuation.

Changing diet.

To return to the effect on the milk yield of alternating A. and B. mixture every fortnight, the result is shown in Fig.III appendix. From the zig-zag nature of the two curves it is clear that the effect of the two mixtures on the milk yield is very different. A change to mixture A. invariably produced a rise and to Mixture B. a fall in the yield.

In order to study the result in more detail, the daily yields of milk for each of the fortnights in which the cows were receiving either mixture A or B respectively have been added together and the average figures are shown graphically in Fig. IV Appendix. Those for Group II are also included.

The curves show that the substitution of B for A mixture was followed by an immediate increase in the rate of milk secretion, a maximum effect being reached on an average in about nine days. After that the stimulating action as judged by the sudden fall in the yield wears off, but the yield remains at a higher level than it was at the introduction of the mixture. On substituting A for B Mixture from the day of its introduction there is a rapid decline in yield for about six days, after that the fall is normal.

The Figures are given below -

Average daily yield of milk lbs.

	Group I.		Group II.
	Mixtures		
Day	A	B	
1	26.7	26.6	24.3
2	27.0	26.2	25.0
3	27.5	25.3	24.8
4	26.9	24.9	24.3
5	28.2	24.3	23.6
6	27.9	24.0	24.2
7	28.4	24.4	23.8
8	28.5	24.1	24.4
9	29.0	24.0	23.5
10	27.8	23.8	23.4
11	28.1	24.0	23.8
12	27.6	23.1	23.3
13	27.8	23.3	23.2
14	27.7	21.2	23.1

The average daily yield of milk per cow fed on A. Mixture was 27.7 lbs. and for the same cows fed on B. Mixture 25.8 lbs.

Water consumed was measured and for each gallon of milk produced, the average amount of drinking water taken by the cows fed on the two mixtures was as follows:-

Weekly average	Mixture A.	Mixture B.
	Gallons	Gallons
1	1.9	2.1
2	2.2	2.0
3	2.8	2.0
4	2.4	2.3
5	2.8	2.5
6	2.8	2.4
7	3.1	2.4
8	3.0	2.5
Average	2.6	2.3

These figures bring out the fact that for each gallon of milk produced more water was consumed by the cows when fed on A. Mixture than when fed on B. Mixture.

Total solids and fat in milk produced from the two mixtures are given below.

	Mixtures			
	A.		B.	
Weekly Averages	Total solids	Fat	Total solids	Fat
1	12.73	3.94	12.75	3.85
2	12.29	3.79	12.65	3.77
3	12.79	3.67	12.70	3.60
4	12.61	3.53	13.11	4.00
5.	11.86	3.42	11.84	3.50
6	11.93	3.32	11.87	3.55
7	12.05	3.43	11.57	3.34
8	12.21	4.25	11.59	3.18
Average	12.31	3.67	12.26	3.60

Here again the above figures show clearly the advantage for the purpose of milk production which A. mixture possesses over that of B.

As pointed out in the introductory remarks the primary object of the present experiment was confined to the single point of testing the effect of frequent changes of diet on milk secretion. The results obtained are distinctly in favour of a constant change of food. In connection with the results the fact must be emphasized that the balance of nutrients in so far as it is possible to judge from analytical data was preserved throughout the test and that increased stimulation of the milk glands was accompanied by loss in weight of the animal. The cause of stimulation is not evident from the data supplied. Arising out of the results is another point of considerable practical importance, namely the remarkable differences in the milk yield obtained by feeding the two mixtures. The results were quite definite since they were confirmed by each repetition of the change. They indicate a partial deficiency in milk producing powers of Mixture B. compared with Mixture A. Considering that each ration contained seven different foods makes the result of greater interest. No difference between the mixtures is evident in the supply of protein fats and carbohydrates and had it not been for the particular method of carrying out this experiment the point may have passed undetected. In any case it brings into prominence the inadequacy of our present method of valuating the milk producing capacity of foods.

To return to the mixtures the main components were as follows:-

Mixture A. Bean meal and Decorticated Cotton Cake
" B. Oat grain and fish meal.

The other components of the ration of which these mixtures formed a part were common to both. The former mixture was more palatable of the two, though the latter was always eaten, it was not taken so readily. Fish meal was selected owing to the fact that in 1918, when cattle foods were scarce, an experiment was carried out by the author to test the value of fish meal as a food for dairy stock, and the results obtained were very favourable.

In order to attempt an elucidation from a chemical standpoint of the difference in milk producing powers of the two mixtures, they have been ground to a fine powder and a complete analysis of the inorganic constituents as well as other tests are being carried out.

In view of the results obtained it was decided to repeat the test in 1922, but with this difference that a larger selection of foods be used in the changing diet.

1922 Experiment

A preliminary experiment commenced on January 3rd and the actual experiment on the 15th. It was completed on May 3rd. Except for the foods employed the details were a repetition of those of last year's experiment.

Daily ration per cow
common to both Groups.

Turnips...............	40	lbs
Hay...................	10	"
Oat straw.............	7	"
Locust bean meal......	½	"
Fish meal.............	½	"

Group I.

Mixture A.			Mixture B.		
Bean meal	4	lbs	Dec.Cotton Cake	3	lbs
Linseed Cake	2	"	Palm nut Cake	1	"
Dried grains	1	"	Crushed Oats	3	"
Thirds	1	"	Bran	1	"

Group II.

One half Mix. A. and one half B.

The above rations each supplied approximately in lbs; Dry matter 27.1; Dig.Protein 2.87; Oil 0.62; Carbohydrates and fibre 13.4. The quantity of meal given was adjusted in accordance with the milk yield of each cow.

Milk Yield

A comparison of the average daily yield of milk for the two groups confirms the results of those of the previous year, namely that frequent changes of diet produces increased stimulation of the mammary glands. The effect however was less marked.

The average weight of the cows in the two groups is shown in the following figures.

Average weight of Cows

	Group I.	Group 2.
1st Fortnight	9.81 cwts	10.19 cwts
2nd "	9.88 "	10.38 "
3rd "	9.81 "	10.38 "
4th "	10.00 "	10.62 "
5th "	9.88 "	10.44 "
6th "	9.69 "	10.25 "
7th "	9.56 "	10.44 "
8th "	9.31 "	10.38 "
Average	9.74 "	10.38 "

Again the cows on the changing diet slightly lost in weight whilst those on the stationary diet showed a slight gain.

Comparing the milk yield of the cows receiving the changing diet, no pronounced difference such as occurred in the previous experiment was found. However Mixture A. has a small but definite advantage in milk producing powers over that of Mixture B. This is shown in the following average daily yields of milk in lbs. for each fortnight for the same cows fed alternately on the two mixtures. Average yields for group II are also included. See also Fig. V. Appendix. 90.

Days	A. Mixture	B. Mixture	Group II.
1	35.4	34.9	32.6
2	35.6	35.3	32.6
3	34.8	35.3	32.2
4	35.1	34.4	32.1
5	34.7	34.8	32.7
6	34.9	34.0	31.8
7	34.9	34.1	32.3
8	35.9	34.6	32.0
9	35.4	34.6	32.2
10	35.4	34.1	31.8
11	36.2	34.3	32.0
12	34.2	34.1	31.8
13.	33.4	33.4	31.7
14	33.3	33.4	30.8
Average	34.9	34.4	32.0

An inspection of tabulated figures showing water consumption and percentages of total solids and fat in milk are practically identical from the two mixtures. The tables are therefore not included.

In concluding this year's experiment the fact must be emphasised that the rations employed were considered to be in every respect most suitable for the purpose of milk production.

Summary

Frequent changes of diet while preserving the balance of supply of proteins, fats and carbohydrates, produced increased stimulation of the mammary glands.

Although the substituted foods in the changing diet were balanced in respect to the supply of nutrients, the fortnightly change brought out unexpected differences in their milk producing powers, notwithstanding the fact that the total number of foods in the ration in one case was seven and in the other nine.

The conclusion is that in addition to the present basis of valuation of foods for nutrition purposes, there is another property especially affecting milk secretion, which requires to be determined.

Considering that a number of other foods were present it is inferred meantime that the property may be due to a cause other than that of accessory food substances.

A P P E N D I X

TABLE III.

PERCENTAGE COMPOSITION of MILK (DAIRY SCHOOL)

Monthly Averages

	March	April	May	June	July	August	September	Average
Water.........	87.89	87.78	87.74	87.43	87.56	87.31	87.62	87.6
Protein.......	3.08	3.10	3.21	3.37	3.22	3.12	3.21	3.19
Fat...........	3.50	3.54	3.56	3.50	3.47	3.87	3.40	3.55
Milk Sugar Ash	5.53	5.68	5.49	5.70	5.75	5.70	5.77	5.66
Total Solids..	12.11	12.32	12.26	12.57	12.44	12.69	12.38	12.40
Specific Gravity........	1.0310	1.0320	1.0320	1.0323	1.0321	1.0316	1.0321	1.0320
Acidity Total.	0.185	0.198	0.192	0.199	0.209	0.223	0.153	0.194
Acidity [1].....	0.099	0.104	0.087	0.096	0.107	0.121	0.054	0.095

(1) After addition of potassium oxalate.

TABLE IV.

PERCENTAGE COMPOSITION of MILK

Monthly Averages

	FACTORY 4.						FACTORY 2.				
	April	May	June	July	August	Average	April	May	June	July	Average
Water.....	87.78	88.02	87.96	87.93	88.16	87.97	88.15	87.59	87.79	88.34	87.97
Protein...	3.14	3.31	3.08	2.82	3.01	3.07	3.01	3.31	3.16	2.89	3.09
Fat.......	3.25	3.00	3.15	3.20	3.30	3.18	3.10	3.20	3.19	2.80	3.07
Milk Sugar Ash.....	5.83	5.67	5.81	6.05	5.53	5.78	5.74	5.90	5.86	5.97	5.87
Total Solids	12.22	11.98	12.04	12.07	11.84	12.03	11.85	12.41	12.21	11.66	12.03
Specific Gravity..	1.0326	1.0332	1.0326	1.0316	1.0314	1.0323	1.0316	1.0329	1.0326	1.0320	1.0323
Acidity Total....	0.180	0.153	0.203	0.216	0.171	0.184	0.158	0.225	0.153	0.150	0.171
Acidity [1]..	0.090	0.050	0.104	0.122	0.081	0.089	0.068	0.126	0.054	0.050	0.075

(1) After addition of potassium oxalate.

TABLE XX.

COMPOSITION of WHEY (DAIRY SCHOOL)

Monthly Averages - Percentages

	March	April	May	June	July	August	September	Average
Water............	92.94	93.03	93.17	93.13	93.12	93.14	93.07	93.09
Protein..........	0.907	0.843	0.856	0.895	0.850	0.869	0.914	0.876
Fat..............	0.27	0.25	0.23	0.22	0.31	0.23	0.28	0.26
Milk Sugar.......	4.79	4.68	4.86	4.89	4.79	4.69	4.79	4.78
Ash..............	0.561	0.412	0.484	0.455	0.485	0.527	0.555	0.497
Undetermined [1]...	0.532	0.785	0.400	0.410	0.445	0.544	0.391	0.497
Total Solids.....	7.06	6.97	6.83	6.87	6.88	6.86	6.93	6.91
Specific gravity.	1.0284	1.0283	1.0281	1.0283	1.0283	1.0280	1.0279	1.0282
Acidity Total....			0.172	0.168	0.205	0.190	0.149	0.177
Acidity [2].......			0.130	0.123	0.157	0.152	0.113	0.135

(1) Principally organic acids.
(2) After addition of potassium oxalate.

TABLE XXI.

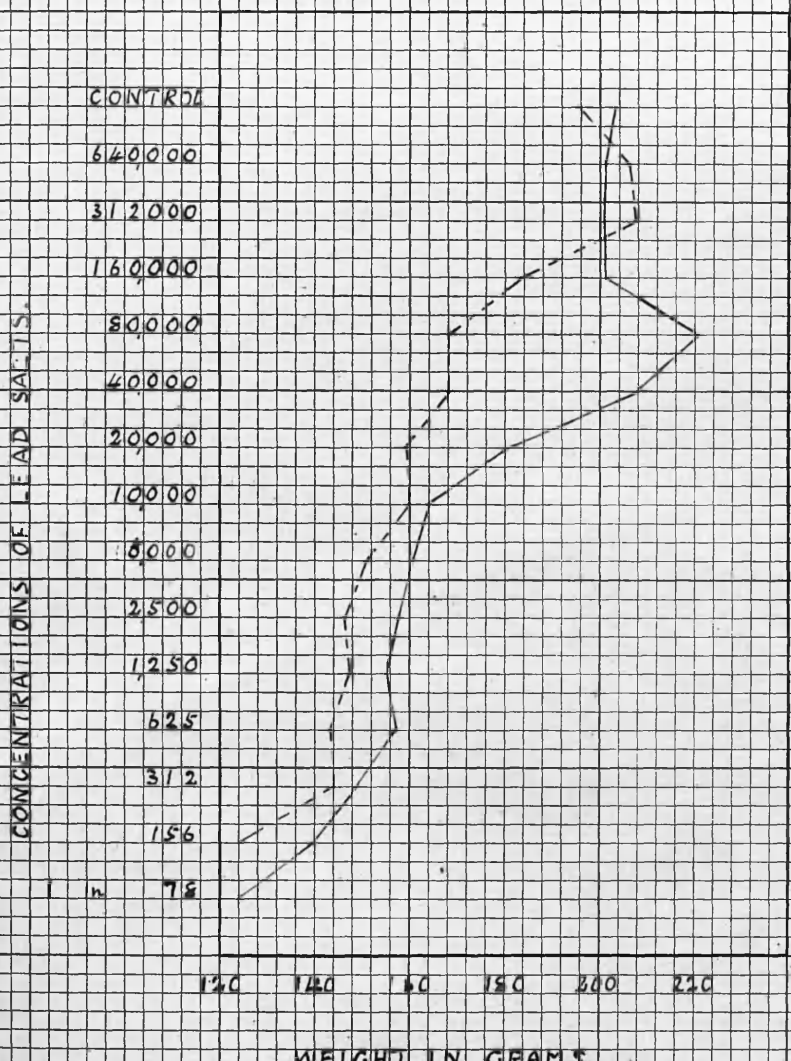
COMPOSITION of WHEY

Monthly Averages - Percentages

	FACTORY 4.						FACTORY 2.				
	April	May	June	July	August	Average	April	May	June	July	Average
Water........	93.16	93.22	93.28	93.21	93.43	93.26	93.12	92.87	93.30	93.2	93.07
Protein......	0.888	0.875	0.875	0.856	0.843	0.867	0.843	0.888	0.875	0.946	0.888
Fat..........	0.12	0.19	0.16	0.16	0.16	0.16	0.21	0.36	0.26	0.30	0.28
Milk Sugar...	4.88	4.84	4.85	4.77	4.68	4.80	4.62	4.74	4.90	4.77	4.76
Ash..........	0.539	0.504	0.547	0.451	0.533	0.515	0.510	0.403	0.412	0.486	0.453
Undetermined and loss[1]...	0.413	0.371	0.288	0.533	0.354	0.398	0.697	0.739	0.453	0.298	0.549
Total Solids.	6.84	6.78	6.72	6.79	6.57	6.74	6.88	7.13	6.90	6.80	6.93
Specific gravity....	1.0283	1.0286	1.0282	1.0279	1.0274	1.0281	1.0277	1.0285	1.0281	1.0282	1.0281
Acidity Total	0.167	0.212	0.236	0.150	0.144	0.182	0.210	0.308	0.198	0.162	0.219
Acidity[2].....	0.129	0.154	0.152	0.108	0.103	0.129	0.161	0.240	0.149	0.124	0.169

(1) Principally organic acids.
(2) After addition of potassium oxalate.

FIG. 1.



LEAD NITRATE

LEAD CHLORIDE

FIG. II

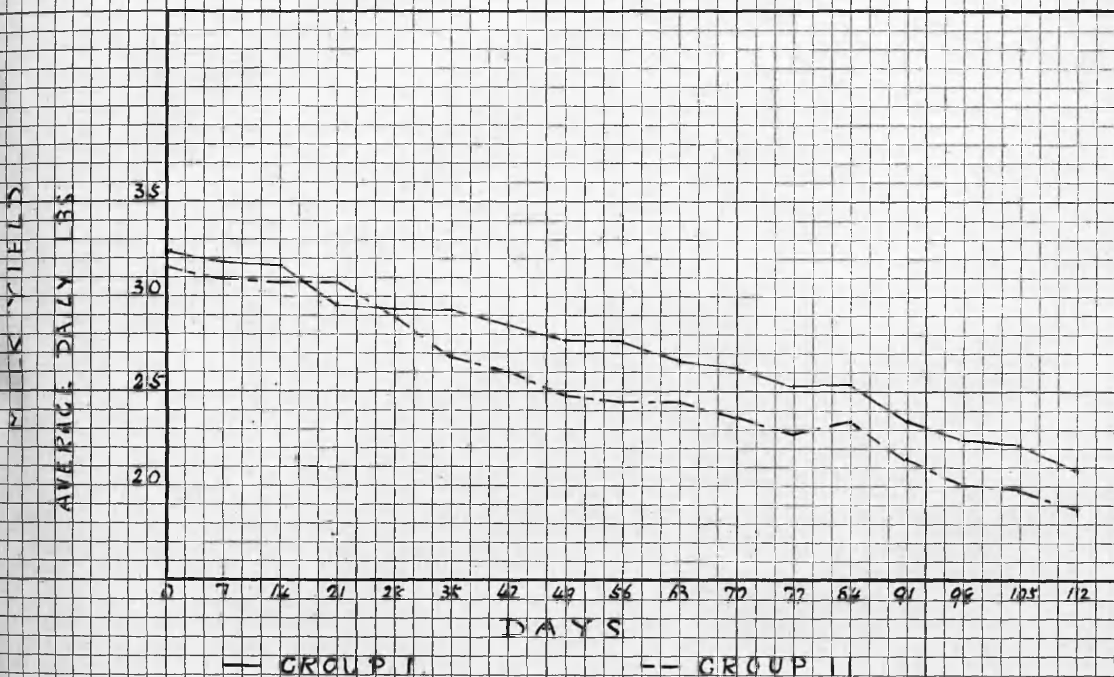
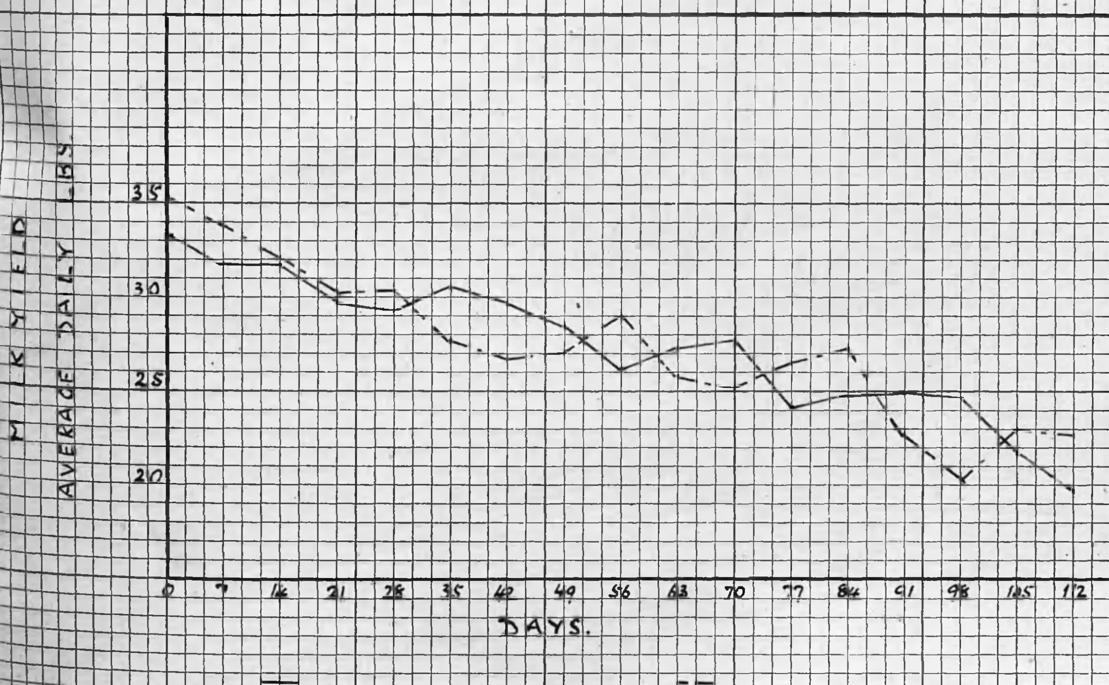


FIG. III



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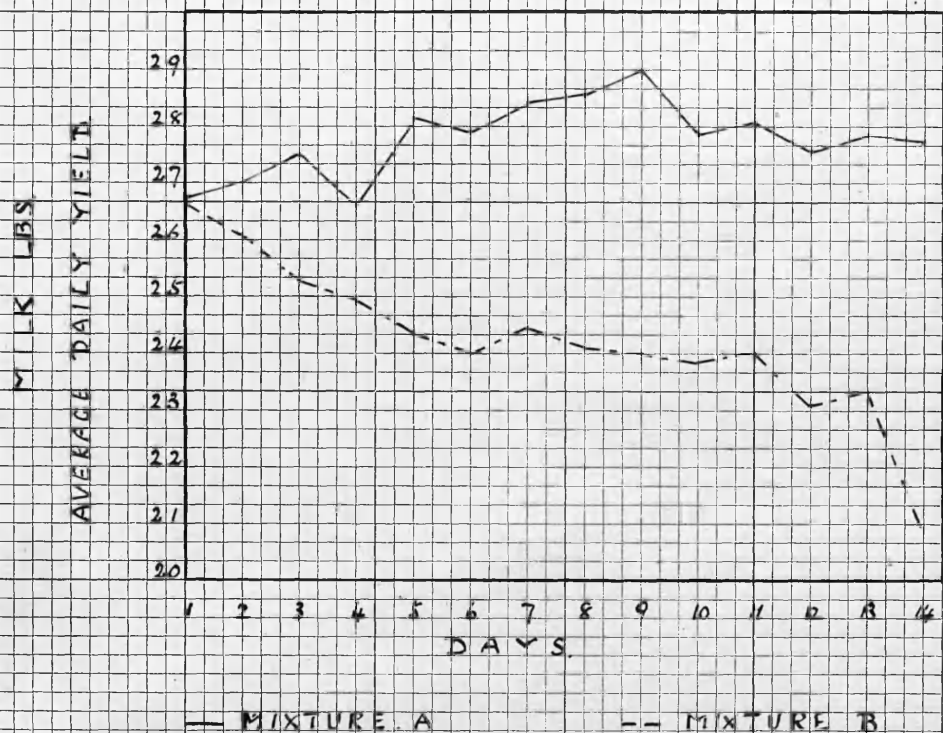
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AVERAGE DAILY YIELD
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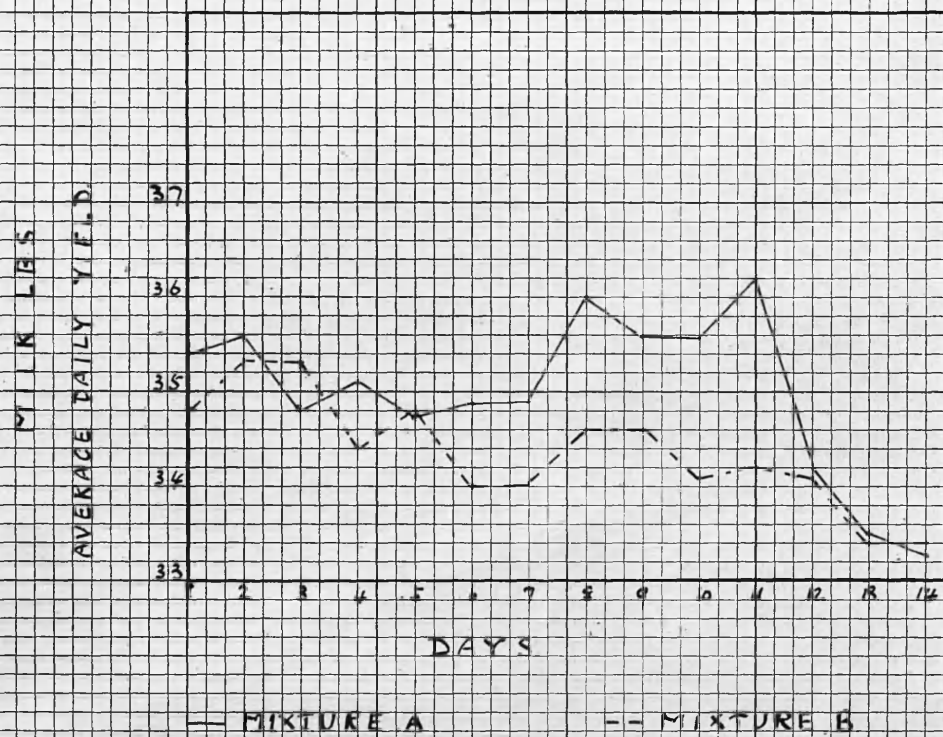
DAYS.
— MIXTURE A
-- MIXTURE B

FIG V.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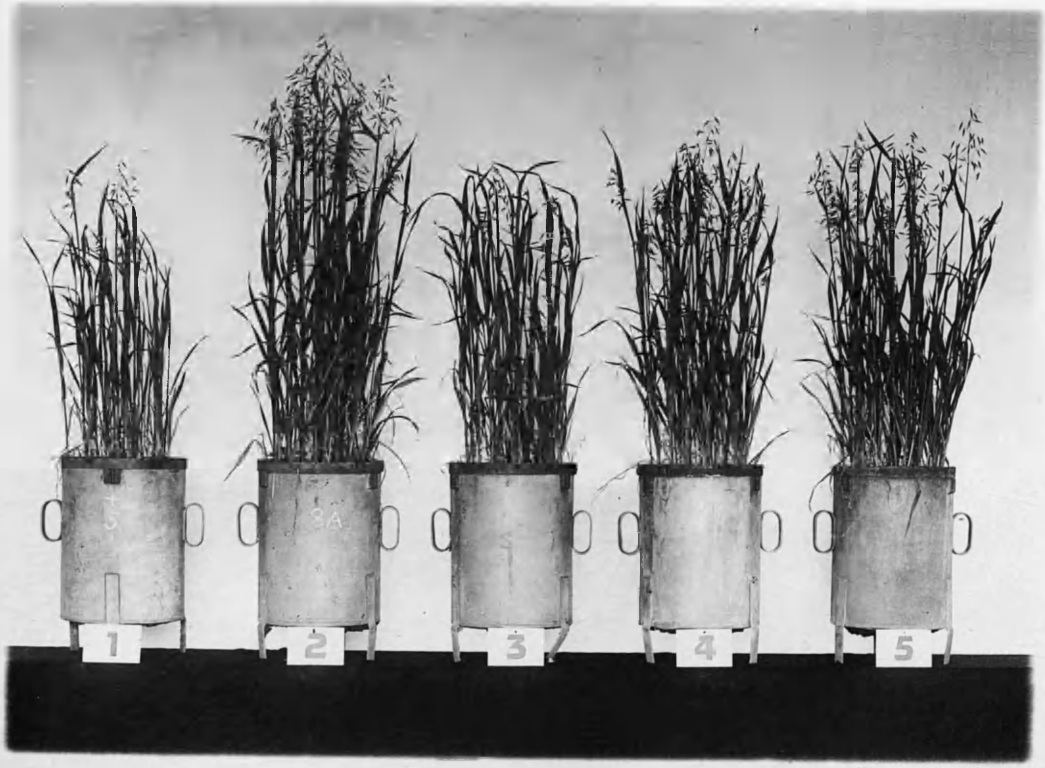
DAYS
— MIXTURE A
-- MIXTURE B

No. 1.



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