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Studies in Mineral Metabolism XXXI.

Minimum Mineral Requirements of Cattle.
(2nd REPORT).*

By

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I. INTRODUCTION.

INCREASED production of milk and beef, like the improvement of herds, is closely associated with good feeding, while improved nutrition can only be brought about if feeds in all their constituents satisfy the requirements of the animals. Minerals, as is probably universally realized in both agricultural research and practice, play an important part in the rations of cattle kept for high production. Furthermore, the feeding of mineral constituents to stock has certainly had at least its fair share of attention during the last dozen years and, like most matters that are suddenly projected into the limelight, has been stressed and emphasized almost to the exclusion of other equally important problems. Perhaps a reason for this decided emphasis of the mineral composition of the diet has been the belief that a lactating cow assimilates probably only about 20 per cent. of the minerals present in her feed, and that consequently milk production is a heavy drain upon the animal's mineral reserves. Then too, the phenomenal improvement in the growth rate of cattle on supplying the naturally deficient mineral, especially phosphorus in certain countries, has given impetus to the study of the mineral constituents of the diet, with the result that while a balanced ration was assumed to contain sufficient minerals for the requirements of stock in the past, in recent years the practice has become prevalent to supply additional minerals to those contained in the ration of dairy cows and even of non-lactating grazing animals.

II. OBJECT OF THE INVESTIGATION.

It was with the view to determine the minimum mineral requirements of growing cattle that a study of this problem was begun in 1925. The first report of the work was published in 1927 while the experiments recorded in this article form a continuation and in some ways an extension of the original object of studying the mineral requirements of growing heifers. As in the first investigation, a pair of Grade Friesland heifers, 30 months old, was placed in each experiment, which was continued through the growing period and until the end of the first three months of the second lactation period. Full details of each experiment and its results are given in the text below.

III. LITERATURE.

No attempt will be made to review recent literature on mineral metabolism, since this subject has recently been discussed by Crichton (1930), who gives a fairly extensive list of references, and although one regrets that the earlier work of investigators like Marek, Wellman and Sjollema in the field of mineral metabolism has been omitted, the review of the literature is undoubtedly a masterly one. Calcium and phosphorus predominate in all the work mentioned. As a matter of fact Crichton deplores the absence of data on the rôle of other inorganic constituents such as magnesium, sodium, potassium and chlorine in animal nutrition, while he states that knowledge of the mineral requirements of growing cattle is regrettably scanty.

The position as set forth by Crichton with regard to the mineral requirement of dairy cattle may be summed up as follows: The literature provides abundant proof for the limitation set upon growth and milk production by deficient phosphorus in the diet under natural conditions of grazing. Under experimental conditions clinical symptoms of aphosphorosis may develop. With regard to calcium the position is not so clear cut. There is no direct evidence that pastures exist that are so deficient in calcium that the growth rate or health of stock is affected, but the author doubts whether such cases do not occur. Calcium deficient diets have given positive results under experimental conditions. Concerning other minerals present in milk, there is almost no information as to the requirements of cattle and " there is no information on which to base even an opinion as to whether or not deficiency of some of these may affect milk yield or health ". Chlorine is liable to be deficient, but this is easily made good by providing rock or ordinary salt. Crichton concludes by expressing the view that the grading up of pastures, although a slow business to ensure adequate mineral intake must be given preference to the addition of inorganic salts to deficient rations.

On the whole we are in agreement with the latter view as an ideal and grading up is comparatively simple where artificial pastures are concerned, but it does not as yet, except in a very small way, fall within the scope of practical agricultural politics where natural, mixed pastures are concerned. It has not yet been shown that phosphorus deficiency, undoubtedly the most widespread mineral deficiency in natural pastures can be made good in this way, so that supplementary feeding of minerals to stock is still an important method of overcoming mineral deficiencies in the natural feed of animals.

An aspect of the cause of phosphorus deficiency in natural pastures which is often overlooked and which throws some light on the puzzle of an existing phosphorus deficiency in practically all sub-tropical areas with seasonal rainfalls not well distributed over the year and hence subject to droughts, lies in the variation of the phosphorus content of pastures with growth. Generally, young succulent grass high in phosphorus is available only for a comparatively short period, while full-grown, mature grass, low in phosphorus, forms the staple food for perhaps eight of the twelve months even in areas where the soil is not necessarily deficient in phosphorus. Values of ·75 per cent. P_2O_5 for young grass may change quite normally to ·03 per cent. for the same grass when mature. Unless pasture improvement develops a short cut to the establishment of pastures consisting mainly of grasses which do not show a remarkable drop in their phosphorus content on maturing, supplementary phosphorus feeding in pastoral countries like South Africa and parts of Australia, will of necessity still be practised for a long time.

Reed and Huffman (1930) report on a five-year mineral feeding investigation with dairy cattle and state that the mineral requirements of dairy cows under conditions of normal production and stall feeding of balanced rations are probably satisfied without the addition of supplementary minerals.

Marek (1924), Wellman (1931) and Marek and Wellman (1932) place great stress upon ratios of minerals to one another which is implied in their conception of "Alkali-alkalizität" and "Erdalkali-alkalizität". These authors explain rickets and allied conditions along lines of abnormal Erdalkali-alkalizität ($MgO + CaO - P_2O_5$ in milligram equivalents per 100 grams dry matter of the ration). A well balanced and healthy ration should show a value between 20 and 25 mgm. equivalents and it is interesting to note that many so-called well balanced rations will not be approved of by these two authors or may even be labelled as definitely rachitic. A vast amount of data obtained mainly from experiments with pigs during a score of years, is presented in two volumes under joint authorship and although much is stated which is not in agreement with the current conception of mineral metabolism, the work certainly demands the serious attention of investigators in this field of research.

IV. DETAILS OF INVESTIGATION.

In the experiments recorded in this paper an attempt was made to subject heifers to extremely low intakes of mineral constituents and, as in the 1925 experiment, roughage was reduced to a minimum in order to obtain a basal ration sufficiently low in all minerals to be satisfactory for all the groups, and so place them on a common basis for comparison as far as food consumption is concerned. It was found that 3½ lb. hay, 5 lb. crushed maize and 5 lb. maize endosperm or fanko, gave a basal ration low in mineral but adequate in other respects in that it produced normal growth if the minerals required were given as a supplement. The total intake of minerals and the mineral composition of the ration are given in Table I.

TABLE I.

Percentage Mineral Composition of Materials used.

Material.	CaO.	MgO.	K_2O.	Na_2O.	P_2O_5.	Cl.	SO_3.	Protein.
Hay.........	·35	·25	1·2	·08	·13	·25	·40	4·8
Maize.......	·03	·24	·36	·16	·5	·08	·16	9·0
Fanko.......	·01	·05	·14	·02	·09	·03	·14	8·0
Blood meal..	·2	·03	·40	1·6	·60	1·0	·8	64·8
Ensilage.....	·10	·07	·3	·01	·1	·06	·1	1·6
Meat meal...	1·1	·04	·4	1·4	1·4	·85	·7	80·0

The initial basal ration of 3·5 lb. hay, 5 lb. crushed maize, 5 lb. fanko, and 20 gm. blood meal contained the following approximate amounts of constituents in grams:—

Constituent	CaO	MgO	K_2O	Na_2O	P_2O_5	Cl	SO_3	Protein.
gm. per head per day	6·8	11·1	29·3	5·7	15·4	6·7	12·9	472

Due to the high cost of fanko the initial plan of omitting maize and increasing the fanko to 10 lb. had to be abandoned. Maize is considerably higher than fanko in minerals, especially phosphorus; so much so that it was impossible to produce an acute phosphorus deficiency on the above ration, and fanko had to be substituted for maize in the phosphorus deficient groups as indicated further in this article. Blood meal was added to improve the "quality" of the protein of which the ration contained sufficient for growing heifers weighing approximately 800 lb. on an average.

The experiment was begun in September, 1930. The animals were stabled under roof in separate feeding boxes over night in a shed. The fanko, maize and blood meal were fed in the afternoon at 3 o'clock when the animals were fastened to their mangers. In the early morning the hay was given which was invariably consumed before half-past 9 when the animals were allowed to go into a fair sized paddock with concrete floor for exercise until stabling time in the afternoon. Water was always available and the minerals were added to the concentrates of the ration. Each animal was placed on the experimental ration immediately after service.

Twenty-six grade Friesland heifers, 2½ years old, were available and pairs, as uniform as possible, were placed in each experiment. With the exception of one, all the animals calved in May and June, 1931. Each was milked for a 90-day period then allowed to dry off and placed with the same bull for a second service in December, 1931.

In February, 1932, 5 lb. maize ensilage was added daily to the basal ration which, therefore, altered the mineral intake per head to the following values: $CaO = 8 \cdot 8$ gm., $MgO = 12 \cdot 5$ gm., $K_2O = 35 \cdot 3$ gm., $Na_2O = 5 \cdot 9$ gm., $P_2O_5 = 17 \cdot 4$ gm., $Cl = 8 \cdot 0$ gm., $SO_3 = 14 \cdot 9$ gm. The protein content of the new basal ration was 510 gm. At the beginning of the second lactation period additional protein was given in the form of 1·5 lb. of meat meal. A summary of the intake of minerals contained in the basal ration over the whole experimental period is given below in grams:—

Period.	CaO.	MgO.	K_2O.	Na_2O.	P_2O_5.	Cl.	SO_3.	Protein.
±17.9.30–18.5.32...	6·8	11·1	29·3	5·7	15·4	6·7	12·9	472
18.5.32–8.8.32....	8·8	12·5	35·3	5·9	17·4	8·0	14·9	510
Last 3 months	15·1	12·8	38·0	15·5	27·0	13·8	19·5	1,026

Prior to the experimental period the roughage of the ration was gradually reduced to that contained in the basal ration. During the preliminary period beginning on 11.5.30 each animal was put on a ration consisting of 3½ lb. lucerne hay, 5 lb. maize, 5 lb. fanko, 20 gm. blood meal, 4 ounces bone meal, until gestation began when the basal ration given for the period 17.9.30–18.5.32 was given instead.

Bearing in mind the basal rations for the periods given, the arrangement of the heifers into twelve groups of one pair each will be clear. An attempt was made to keep the total intake of minerals in all the groups constant except the one constituent which was kept low intentionally. The quantities of mineral supplements given were based upon the composition of 12 lb. good English hay and an attempt was made to approximate the quantity of minerals in the ration and supplement to that which would be ingested by heifers of this type on English pasture. The following table contains a schematic representation of the experiment and indicates at the same time the intake of minerals in the various groups.

TABLE II.

Daily intake of Minerals per head in Basal Ration plus Mineral Supplement.

D.O.B. Nos.	Experiment.	Period.	CaO.	MgO.	K_2O.	Na_2O.	P_2O_5.	Ce.	SO_3.
	I.								
3641	Low Ca and low P......	19.7.30 to 17.2.32	6·8	21·4	76·3	18·9	15·4	57·4	12·9
3648		18.2.32 to 17.5.32	6·3	16·3	72·3	16·7	8·4	56·2	12·9
		18.5.32 to 8.8.32	8·3	17·3	78·3	16·9	8·4	57·5	14·9
		Last three months	14·8	18·0	81·0	27·5	17·4	63·3	19·5
	II.								
3659	Low P.................	19.7.30 to 17.2.32	51·6	21·4	76·3	18·9	15·4	57·4	12·9
		18.2.32 to 17.5.32	51·1	16·4	72·3	15·8	6·4	56·2	12·9
		18.5.32 to 8.8.32	53·1	17·8	80·3	16·0	8·4	57·5	14·9
		Last three months	59·1	20·1	83·0	25·6	18·0	65·3	19·5
	IIIA.								
3643	Low Ca.................	19.7.30 to 17.5.32	6·8	21·4	74·0	18·9	45·1	49·8	12·9
3655		18.5.32 to 8.8,32	8·8	22·8	80·0	19·1	46·8	50·2	14·9
		Last three months	15·1	23·1	80·0	28·7	56·7	56·0	19·5
	IIIB.								
3640	Low Ca and low Mg.....	19.7.30 to 17.5.32	6·8	11·1	101·3	18·9	45·1	48·9	12·9
3650		18.5.32 to 8.8.32	8·8	12·5	107·3	19·1	46·8	50·2	14·9
		Last three months	15·1	12·8	110·0	28·7	56·7	56·0	19·5
	IV.								
3642	All mineral deficiency except P. and Ca	19·7·30 to 17.5.32	47·1	11·1	29·3	5·7	45·1	6·7	12·9
3649		18.5.32 to 8.8.32	49·1	12·5	35·3	5·9	46·8	8·0	14·9
		Last three months	55·4	12·8	38·0	15·5	56·7	13·8	19·5

TABLE II—(*continued*).

D.O.B. Nos.	Experiment.	Period.	CaO.	MgO.	K_2O.	Na_2O.	P_2O_5.	Cc.	SO_3.
	V.								
3651	Low Na and low Cl.....	19.7.30 to 17.5.32	56·1	21·4	75·0	5·7	45·1	6·7	12·9
3646		18.5.32 to 8.8.32	53·6	22·8	80·0	5·9	46·8	8·0	14·9
		Last three months	59·9	23·1	80·0	15·5	56·7	13·8	19·5
	VI.								
3658	Low Cl................	19.7.30 to 8.8.32	51·6	21·4	76·3	18·9	45·1	6·7	12·9
3675		18.5.32 to 8.8.32	53·6	22·8	80·0	19·1	46·8	8·0	14·9
		Last three months	59·9	23·1	80·0	28·7	56·7	13·8	19·5
	VII.								
3653	Low Na...............	19.7.30 to 17.5.32	51·6	21·4	76·3	5·7	45·1	57·4	12·9
		18.5.32 to 8.8.32	53·6	22·8	82·3	5·9	46·8	58·7	14·9
		Last three months	59·9	23·1	80·0	15·5	56·7	64·5	19·5
	VIII.								
3673	Low K................	19.7.30 to 17.5.32	51·6	21·4	29·3	18·9	45·1	57·4	12·9
3656		18.5.32 to 8.8.32	53·6	22·8	35·3	19·1	46·8	46·8	14·9
		Last three months	59·6	23·1	38·0	28·7	56·7	53·8	19·5
	IX.								
3677	All mineral sufficiency, plus KI	19.7.30 to 17.5.32	47·1	21·4	76·3	18·9	45·1	57·4	12·9
3652		18.5.32 to 8.8.32	49·1	22·8	82·3	19·1	46·8	57·4	14·9
		Last three months	55·4	23·1	85·0	28·7	56·7	64·5	19·5
	X.								
3645	All mineral sufficiency ..	19.7.30 to 17.5.32	47·1	21·4	76·3	18·9	45·1	57·4	12·9
		18.5.32 to 8.8.32	49·1	22·8	82·3	19·1	46·8	58·7	14·9
		Last three months	55·4	23·1	85·0	28·7	56·7	64·5	19·5

It will be seen from Table II that eleven groups each comprising a pair of heifers were formed. Originally there were 12 pairs but the group receiving a supplement of sodium fluorine soon showed clinical symptoms of fluorine poisoning as reported in an article by Du Toit and others (1932) and was perforce eliminated when the animals died, about 12 months after the beginning of the experiment. On the whole the mineral intake remained constant for all groups except, of course, that the constituent intended to be low in the ration of a particular group is restricted to the amount contained in the basal ration only. For instance, the phosphorus intake of animal No. 3659 viz. 15·4 gm. in Experiment II is intentionally different from that of the animals in Experiment IV, but the amount of other minerals contained in these two rations is the same for both groups.

In Experiments I and II the basal ration containing 5 lb. fanko and 5 lb. maize was changed on 18.2.32 to 10 lb. fanko or maize endosperm and no maize, thereby decreasing the phosphorus intake very considerably (from 15·4 to 6·4 gm.), without altering the rest of the composition of the ration markedly.

In the following pages each of the groups or experiments set forth in Table II will be considered separately and comparisons made with the control animal in Experiment X, the ration of which was supplemented to be sufficient in all the minerals studied. Unfortunately animal 3639, the second control heifer, was injured and had to be eliminated from the experiment. One of the heifers in Experiment II died of Heartwater (rickettsiosis) shortly after the beginning of the experiment and left only one in that group. It is unfortunate that only one control heifer remained in this investigation, but if a comparison is made of the growth curve of this heifer, viz. No. 3645 with that of the control group kept under similar conditions in the experiments described by Theiler, Green and Du Toit (1927) it will be seen that this heifer can well be regarded as the standard of comparison in the present investigation. Her increase in weight, general health, food consumption, etc., agree well with those of the controls in the original experiment.

Reference to the weight curves will make the basis of comparison of the groups clear. Naturally the animals in the different groups did not calve on the same date, yet it is obviously necessary, if comparisons are to be made, to compare a lactating animal of a group with its mate during the same period of lactation. The same applies when groups are compared. Hence the two successive dates of calving of all the animals were made to coincide. The two periods of lactation and of gestation will then obviously coincide. The length of the rest periods were different and these are indicated in figures on each curve. Direct comparisons between two animals are, therefore, made for the respective gestation and lactation periods in the graphic representations submitted below.

The animals were weighed at monthly intervals, when samples of blood were drawn for analysis. Food consumption was registered from time to time as stated in the discussions of the individual experiments. Milk production was registered and monthly milk samples analysed for minerals as well as for the organic constituents. This aspect of the work will be reported on in detail by one of the authors (J. W. G.) at a later date.

The basal ration of 3·5 lb. hay, 5 lb. fanko, 5 lb. maize, 20 gm. blood meal was given daily for the first 20 months of the experiment, when for reasons explained in the general discussion of the work, 5 lb. of maize ensilage was given in addition. Actually, therefore, the animals were not receiving enough protein for milk production during the first lactation period, while during second lactation protein deficiency was rectified by the daily addition of 1·5 lb. meat meal (80 per cent. protein.)

The basal rations for the three periods of the investigation were as follows:—

Period.	Daily Basal Ration.
1. Beginning of first gestation (Sept., 1930)–17.5.32	3·5 lb. hay, 5 lb. crushed maize, 5 lb. fanko, 20 gm. blood meal.
2. 18.5.32–8.6.32............	Basal ration of 1st period, plus 5 lb. maize ensilage.
3. Last 3 months of investigation	Basal ration of 2nd period, plus 1·5 lb. meat meal (80 per cent. protein).

Reference to Table II reveals 3 corresponding periods of mineral intake as suggested by the above, except in Experiment I which has been explained elsewhere. Food consumption was registered daily and the animals inspected for clinical symptoms of disease or of deficiencies.

Experiment I.

Low calcium and low phosphorus but adequate in other respects.

History.

No. of animal......................	No. 3641	No. 3648	No. 3645 (control.)
Date when experimental ration began, i.e. beginning of 1st gestation......	28.8.30	1.9.30	29.10.30
Date of calving.....................	4.6.31	3.6.31	19.7.31
End of lactation....................	4.9.31	3.9.31	19.10.31
End of rest period, i.e. beginning of 2nd gestation........................	15.11.31	5.3.32	14.12.31
Date of calving.....................	26.8.32	12.12.32	25.9.32
Date of conclusion of experiment......	23.9.32 (killed *in extremis.*)	12.3.33	25.12.32

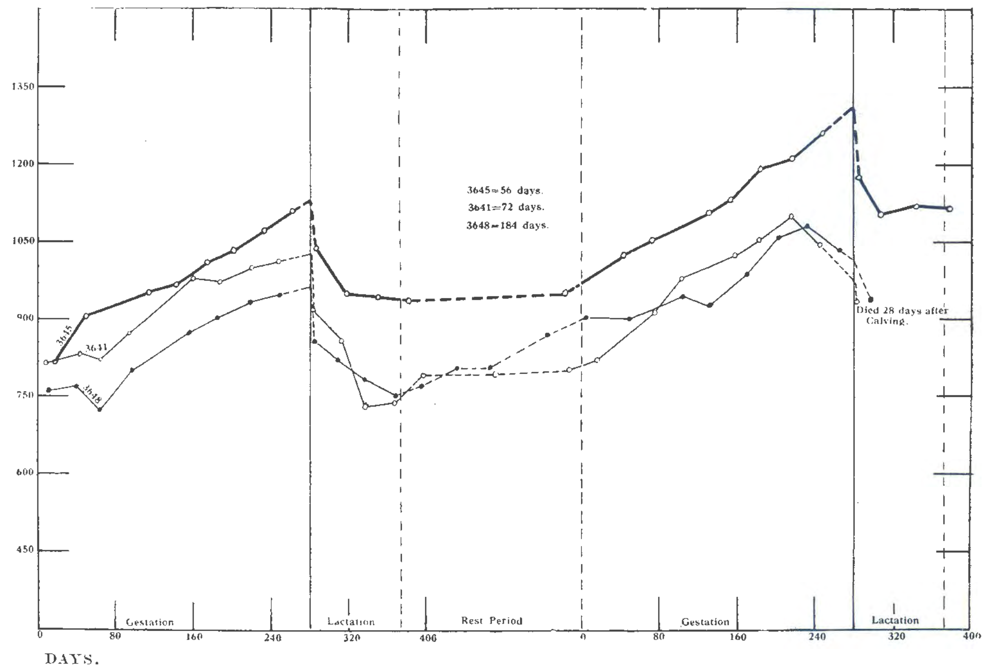
The basal ration of 3½ lb. hay, 5 lb. crushed maize, 5 lb. fanko, and 20 gm. blood meal was given, plus 25 gm. NaCl, 15 gm. $Mg(OH)_2$ and 75 gm. KCl. The mineral constituents in the day's food came to 6·8 gm. CaO, 15·4 gm. P_2O_5, 21·4 gm. MgO, 76·3 gm. K_2O, 18·9 Na_2O, 57·4 gm. Cl and 12·9 gm. SO_3. Except for phosphorus and calcium the mineral content of this ration was the same as that given to the control animal No. 3645 on a ration sufficient in all minerals. The ration is potentially alkaline with a positive Erdalkali-alkalizität of approximately 24 milligram equivalents and a ratio of CaO to P_2O_5 of 1:2·2.

It should be stated, however, that this experiment was conceived with the intention of producing deficiencies in phosphorus and calcium apart from the fact whether a favourable or unfavourable calcium phosphorus ratio, or Erdalkali-alkalizität was present or not. These factors may and probably do influence the severity of a deficiency, and its effect upon the system; but if an absolute deficiency can be brought about, factors influencing its effect upon the organism or its acuteness must be of secondary importance. That was the attitude towards such factors at the beginning of the investigation and hence they were left out of consideration, although it was realized that they would probably not be without effect. This course was adopted in the belief that the deficiency would be sufficiently acute in any case to be recognized in spite of favourable factors.

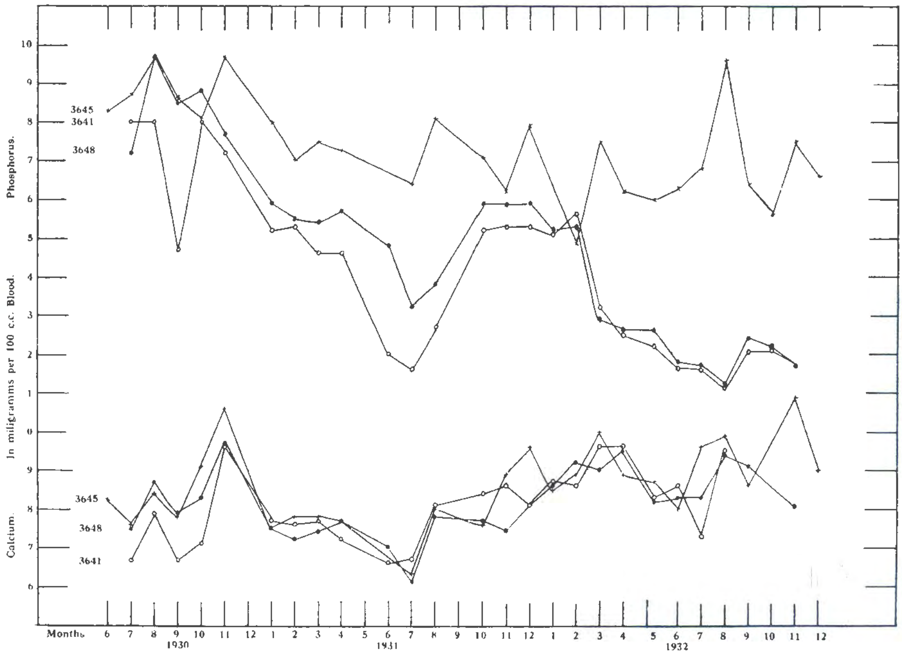
In an experiment now being undertaken calcium and phosphorus metabolism is being studied on a broader basis with due regard to the effect upon the absorption, retention and utilization of these two constituents, of modifying factors such as varying ratios and changes in the Erdalkali-alkalizität in Marek's sense.

The comparative weight increases of animals 3641 and 3648 in Experiment I are given in Graph I. The weight curve of the control animal 3645 is given on the same chart for purposes of comparison. A graphic representation of the inorganic phosphorus and of calcium in the blood of these three animals is given in Graph II.

Apparently both animals stood the strain of their first pregnancy well. During lactation the heavier producer 3641 lost more weight, showed hardly any improvement during her comparatively short rest period of 72 days, and withstood the strain of gestation until about 2 months before calving, when she began to lose weight rapidly, and it became obvious that she would not live much longer. She calved normally when in poor condition, continued losing weight,



GRAPH I.—Weights of Animals in Pounds.



GRAPH II.—Inorganic Phosphorus and Calcium.

and when about a month after calving she was unable to rise and in a miserable state, she was killed in extremis. No. 3648 fared slightly better. She was a lighter milk producer and had a comparatively long rest period of 184 days during which she showed great improvement. In spite of her better chances this animal also began to lose weight before calving, was reduced to very poor condition during lactation, could hardly walk on account of acute styfsiekte (aphosphorosis), and died of shock following dislocation of the hip in a fall, 10 days before the end of lactation.

Both animals did poorly when compared with the control and developed clinically recognizable stywesiekte, early in the experiment. This condition lasted throughout with improvement during the rest period when the phosphorus intake was most probably not far short of the requirements of the animals. The amount of inorganic blood phosphorus confirms this view. It rose after the first lactation to a normal figure of over 5 mgm. per 100 c.c. until the 5 lb. maize in the basal ration were substituted by 5 lb. fanko in February, 1932. After that period the inorganic phosphorus dropped indicating aphosphorosis which lasted until the end of the experiment. Furthermore, Graph II also indicates that the animals in Experiment I most probably did not feel the effects of the low phosphorus in the ration before the onset of first lactation.

The values for calcium in the blood of these animals give no indication as to whether a calcium deficiency existed.

For a comparison of the intake and outgo of calcium and phosphorus in the food on the one hand and in the milk on the other, reference must be made to Tables III and IV.

TABLE III.

Daily Mineral Intake in Feed and Output in Milk for First Lactation.

Group.		D.O.B.	CaO.		P_2O_5.		MgO.		K_2O.		Na_2O.		Cl.	
			Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.
I.	Low Ca and P.........	3641	6·8	16·4	15·4	30·0	21·4	18·4	76·3	22·6	—	6·7	—	9·3
		3648	6·8	11·7	15·4	21·7	21·4	1·3	76·3	16·1	18·9	4·8	51·4	6·6
II.	Low P.................	3659	51·6	17·1	15·4	32·0	21·4	1·9	76·3	24·6	18·9	7·0	57·4	9·8
IIIA.	Low Ca...............	3643	—	14·8	45·1	27·5	21·4	1·7	74·0	20·4	—	6·2	—	8·4
		3655	6·8	13·2	45·1	24·6	21·4	1·5	74·0	18·3	18·9	5·4	48·9	7·5
IIIB.	Low Ca...............	3640	—	—	—	—	—	—	—	—	—	—	—	—
	Low Mg...............	3650	6·8	15·6	45·1	29·0	11·1	1·8	101·3	21·5	18·9	6·4	49·9	8·9
IV.	All min. low except Ca and P.	3642	—	11·7	45·1	21·7	21·4	1·3	29·3	16·1	—	4·8	—	6·6
		3649	47·1	11·7	45·1	21·7	21·4	1·3	29·3	16·1	5·7	4·8	6·7	6·6
V.	Low Na, Cl............	3651	—	10·9	45·1	20·3	21·4	1·2	75·0	15·0	—	4·5	—	6·2
		3646	51·6	16·4	45·1	30·4	21·4	1·8	75·0	22·6	5·7	6·7	6·7	9·3
VI.	Low Cl................	3658	—	15·6	45·1	29·0	21·4	1·8	76·3	21·5	—	6·4	—	8·9
		3675	51·6	14·8	45·1	27·9	21·4	1·7	76·3	20·4	18·9	6·2	6·7	8·4
VII.	Low Na................	3653	51·6	17·2	45·1	32·0	21·4	1·9	76·3	23·6	5·7	7·0	57·4	9·8
VIII.	Low K.................	3656	—	—	—	—	21·4	—	—	—	—	—	—	—
		3673	51·6	10·9	45·1	20·2	21·4	1·2	29·3	15·0	18·9	4·5	57·4	7·1
IX.	All min. sufficient + KI	3677	—	12·5	—	23·2	21·4	1·4	—	17·2	—	5·1	—	6·2
		3652	47·1	11·7	45·1	23·2	21·4	1·3	76·3	16·1	18·9	4·8	57·4	6·7
X.	All min. sufficient.....	3645	47·1	12·5	45·1	23·6	21·4	1·7	76·3	17·2	18·9	5·1	57·4	7·1

TABLE IV.

Daily Mineral Intake in Feed and Outgo in Milk for Second Lactation.

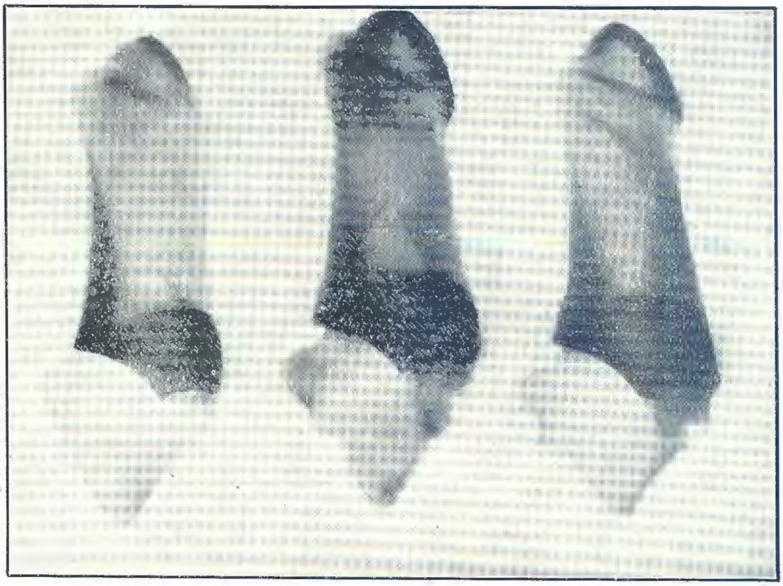
Group.		D.O.B.	CaO.		P_2O_5.		MgO.		K_2O.		Na_2O.		Cl.	
			Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.	Intake.	Outgo.
I	Low Ca and P.	3641	14·8	—	17·4	—	18·1	—	81·0	—	27·5	—	—	—
		3648	14·8	—	17·4	—	18·1	—	81·0	—	27·5	—	63·3	—
II.	Low P.	3659	59·1	—	18·0	—	20·1	—	83·0	—	25·6	—	65·3	—
IIIA.	Low Ca.	3643	15·1	18·7	56·7	35·0	23·1	2·1	80·0	25·8	28·7	7·8	—	10·6
		3655	15·1	21·0	56·7	39·1	23·1	2·4	80·0	29·0	28·7	8·6	56·0	12·0
IIIB.	Low Ca.	3640	15·1	18·0	56·7	33·3	12·8	2·0	110·0	24·8	28·7	7·4	—	10·2
	Low Mg.	3650	15·1	20·3	56·7	37·7	12·8	2·3	110·0	28·0	28·7	8·3	56·0	11·3
IV.	All min. low except Ca and P.	3642	55·4	17·2	56·7	32·0	23·1	1·9	38·0	23·6	15·5	7·0	—	9·8
		3649	55·4	18·0	56·7	33·3	23·1	2·0	38·0	24·8	15·5	7·3	13·8	10·2
V.	Low Na, Cl.	3651	59·9	—	56·7	—	23·1	—	80·0	—	15·5	—	—	—
		3646	59·9	—	56·7	—	23·1	—	80·0	—	15·5	—	13·8	—
VI.	Low Cl.	3658	59·9	—	56·7	—	23·1	—	80·0	—	28·7	—	—	—
		3675	59·9	—	56·7	—	23·1	—	80·0	—	28·7	—	13·8	—
VII.	Low Na.	3653	59·9	23·4	56·7	43·5	23·1	2·4	80·0	32·2	15·5	9·6	64·5	13·3
VIII.	Low K.	3656	59·9	—	56·7	—	23·1	—	38·0	—	—	—	—	—
		3673	59·9	—	56·7	—	23·1	—	38·0	—	28·7	—	64·5	—
IX.	All min. sufficient + KI.	3677	55·4	13·2	56·7	24·6	23·1	1·5	85·0	18·2	—	5·4	53·8	7·5
		3652	55·4	—	56·7	—	23·1	—	85·0	—	28·7	—	—	—
X.	All min. sufficient.	3645	—	—	—	—	23·1	—	85·0	—	28·7	—	—	—
			55·4	18·0	56·7	33·3	23·1	2·0	85·0	24·8	28·7	7·3	64·5	10·2

From the above tables it is abundantly clear that 3641 was definitely suffering from a more acute phosphorus deficiency than 3648. The former animal actually secreted daily in the milk almost exactly twice as much phosphorus as was contained in the food. No wonder, therefore, that 3641 could not stand the conditions of the experiment at all.

With regard to calcium deficiency, the position was not much better, both animals receiving in the food only about half or less than half the calcium secreted in the milk. Both animals developed pica early in the experiment and were ferocious earth eaters whenever the opportunity was offered. Unfortunately the animals developed sore feet on the concrete floor where they were allowed to exercise, and had to be transferred to an adjoining sandy paddock for short periods on several occasions. The sand in this paddock contained ·2 per cent. CaO and ·0003 per cent. P_2O_5. Some of the phosphorus and calcium in the sand went to rectify the shortage of these two minerals, especially the Ca in the rations. Furthermore, the animals were given tapwater which ensured an additional intake of CaO per day of ·7 gm. The fact remains, however, that a calcium deficiency, although not recognisable clinically, most probably existed in this experiment as well as a definite aphosphorosis.

Table V gives the monthly milk yield of all the animals during both lactation periods in this experiment. Animal 3641 showed remarkable drops in the successive monthly milk yields. This decrease was not noticed in the smaller production of 3648 or in the control.

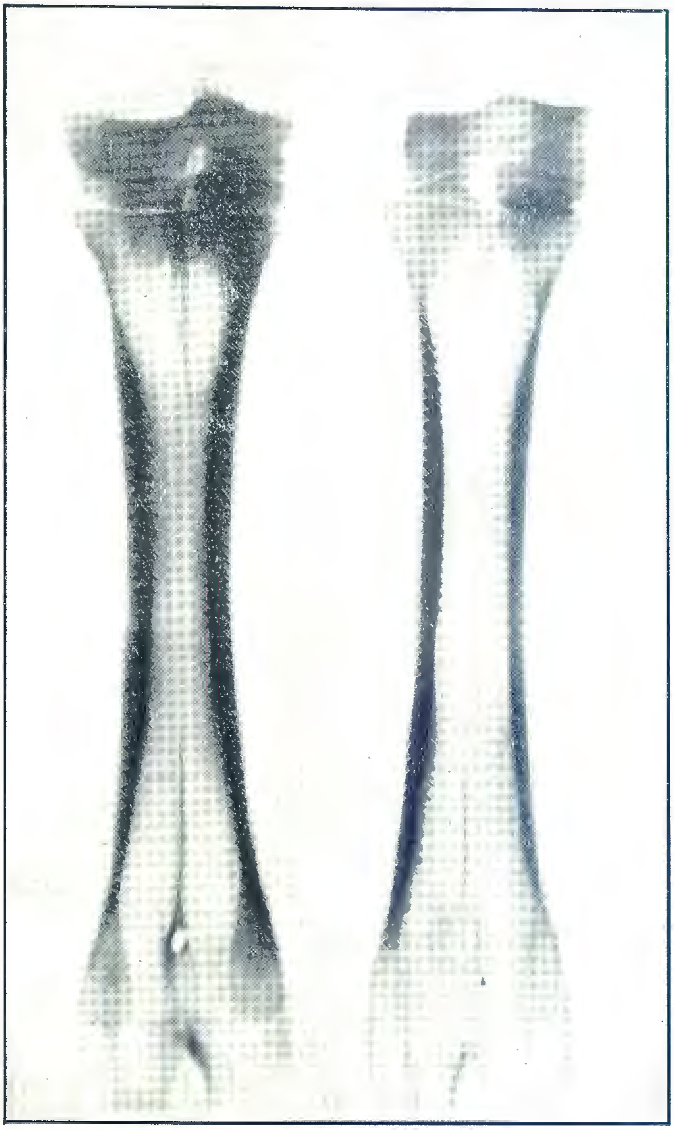
FIGURE 1.



No. 3659. Low P. — Normal. Animal. — No. 3641. Low Ca and Low P.

Reproduction of X-ray photographs of selected bones of 3641 and of the control are given below and throw light upon the experimental condition from another angle. For convenience, bones of animal 3659 discussed in Experiment II have been included (see Figures 1 and 2) and will be considered along with those of the control animal and of 3641.

FIGURE 2.



Normal. Animal. No. 3641. Low Ca and Low P.

* The normal tarsal and metatarsal bones show a dense and well-defined cortex, the outline of which is very sharply marked off from the medullary cavity. The medullary cavity is smaller than is the case in the experimental animal owing to the greater development of the compact tissue. The epiphysial trabeculae are well marked. The junction of the third and fourth metatarsal bones is shown by a dark line at both extremities, which disappears toward the middle third of the bone. The greater density of the tarsal bones is shown by the darker shade in the photograph.

In the experimental animal these bones show a narrower and less dense cortex with a lack of definition in outline. The medullary cavity is larger and the spongy bone at the epiphysis not so dense. The tarsal bones also show a lighter shade in the photograph due to being less dense.

The Os Calcanei.

The contrast in density of the os calcanei in the control and experimental animals is very well illustrated in the photographs. The shadow in the bones of the control animal is much deeper. The cortex of the bones of the experimental animal is much more transparent and lacks a definite border line.

The os calcanei is an excellent bone in which to demonstrate the difference in bone density. The darker shadow shown by the more dense bone of the control animal is quite apparent from the photograph.

Experiment II.

Low Phosphorus but adequate in Other Respects.

History.

No. of animal	No. 3659.	No. 3645 (control.)
Date experimental ration began beginning first gestation	15.9.30	29.10.30
Date of calving	21.6.31	19.7.31
End of lactation	21.9.31	19.10.31
End of rest period beginning second lactation	14.11.31	14.12.31
Date of calving	23.8.32	25.9.32
Date of conclusion of experiment	Died 4.10.32 (weakness and exposure).	25.12.32

The basal ration was in complete agreement with that of Experiment I, except that calcium carbonate was added to increase the daily intake of Ca to 47·1 gm.—The same as that of the control animal, No. 3645. The weight curves are given in Graph III. Graphic representations of the inorganic phosphorus content of the blood are given in Graph IV.

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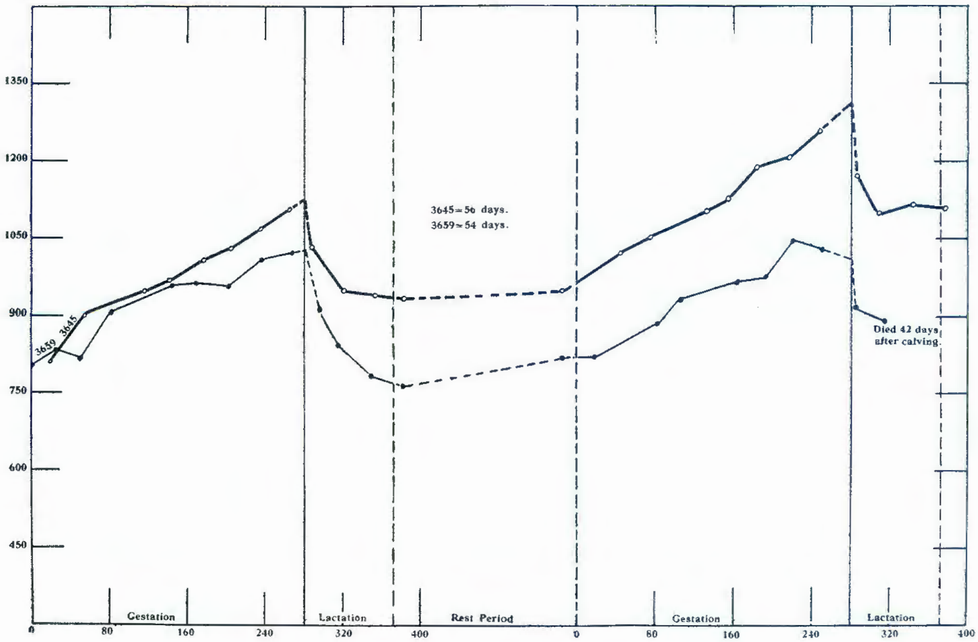
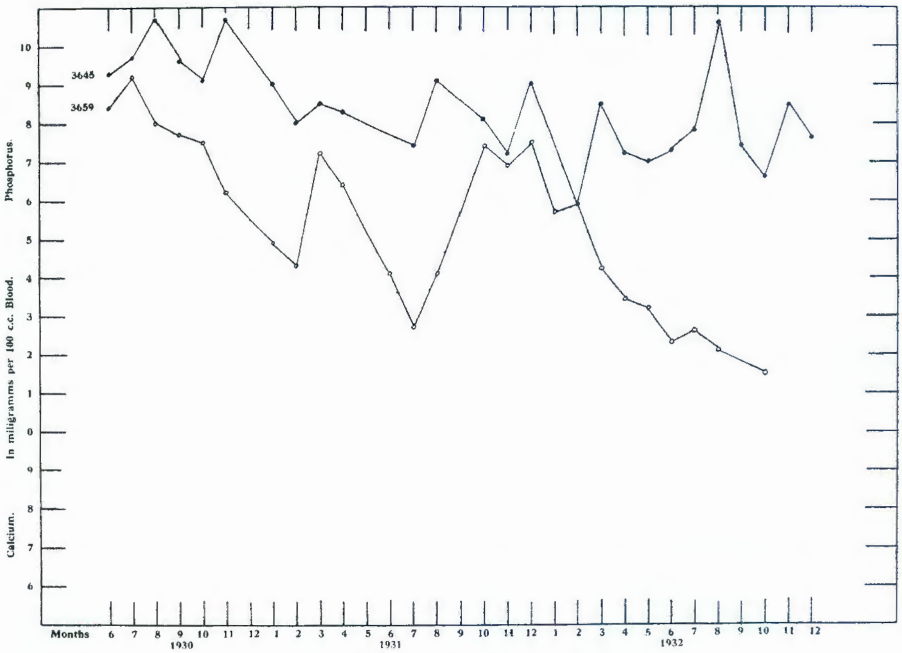
* A description of the radiograms was kindly given by J. Quinlan, F.R.C.V.S., D.V.Sc., etc.



DAYS.

Graph III.—Weights of Animals in Pounds.



Graph IV.—Blood Analysis.

A study of the Graphs III and IV given above reveals that in many ways the course of this experiment follows that of the first experiment very closely. An appreciable difference in weight between 3659 and the control 3645 appeared only when the first lactation period began. The rest periods are about equally long and 3659 showed signs of improvement which continued until shortly before the second calving, when the animal began to drop in weight; her condition, already very poor, became worse as she was a heavy milker. Styfsiekte developed early in the experiment and became worse during lactation. Just over a month after calving the animal, then in a miserable condition, was unable to rise and was unfortunately left exposed to wind and rain during the night when she died. A post-mortem examination revealed a broken pelvis and several broken ribs. The bones were kept for pathological study at a later date.

The monthly blood analyses for inorganic phosphorus confirmed the observation made in regard to the weight curves. During the rest period the animal showed a normal value for blood phosphorus which rapidly dropped in February, 1932, when fanko was substituted for maize as in Experiment I. Low inorganic phosphorus in the blood continued until the end of the experiment.

The daily intake of minerals in the ration and output in the milk is represented in Tables III and IV.

It is apparent from Table III that No. 3659 was actually secreting more than twice the amount of phosphorus in her milk than she was getting in her food. No wonder, therefore, that her milk production during the third month was markedly less than that of the first month ($\pm$ 200 lb. less). The phosphorus deficiency in addition to the protein shortage must have made the position almost unbearable during lactation or perhaps protein shortage helped to limit milk production and in that way saved the animal from further depleting her system to supply the necessary phosphorus. At all events phosphorus deficiency during lactation was an established fact. From Graph IV it is evident that phosphorus deficiency existed not only during lactation but also towards the end of the first gestation period, and from February, 1932, when fanko was increased at the expense of maize, until the animal's death.

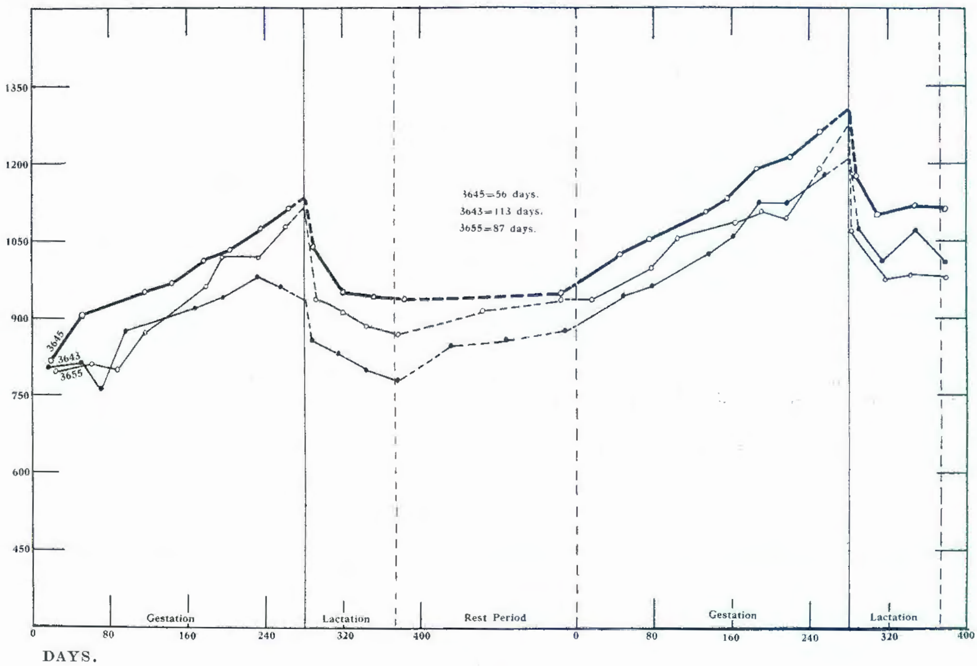
Calcium was abundantly present throughout, and blood calcium did not appear to be different from that of the control or from that of the animals in Experiment I.

Complete data with regard to the mineral content of the blood of the bovines for the full period of the investigations reported on in this paper will be found in the publication by Groenewald (1934). These analyses are omitted from this article for reasons of economy and to obviate repetition.

A comparison of Experiments I and II leaves doubt as to what the effect of low calcium was in the former experiment. The history of animal No. 3641, a high producing cow, in Experiment I on low Ca and P, follows that of No. 3659, also a high producing cow on low phosphorus only, in Experiment II, pretty closely, both having stood the strain of the first lactation period with loss in weight, development of acute styfsiekte and general setback. The strain of the second gestation period was too severe and both succumbed about a month after the birth of the second calf. A comparison of these two experiments with No. III will be made after discussion of the latter. For the present it can only be said that the effects of a phosphorus deficiency on animal No. 3659 was as fatal as that of a phosphorus deficiency plus low calcium on No. 3641—two animals directly comparable as regards milk production.

Experiment III.

Two pairs of heifers were included in this experiment, (A) one pair was placed on low calcium ,and high magnesium), while (B) the other pair received both low calcium and low magnesium. The higher magnesium in A incidentally improved the Erdalkali-alkalizität in Marek's sense, while the magnesium was kept low in the other case, although hardly sufficiently so to be of any significance in an attempt to approach Becka's idea (1929) of the good effect of magnesium upon calcium metabolism. Reference to Table II shows the intake of CaO to be 6·8 gm. daily and MgO 21·4 and 11·1 gm. respectively.

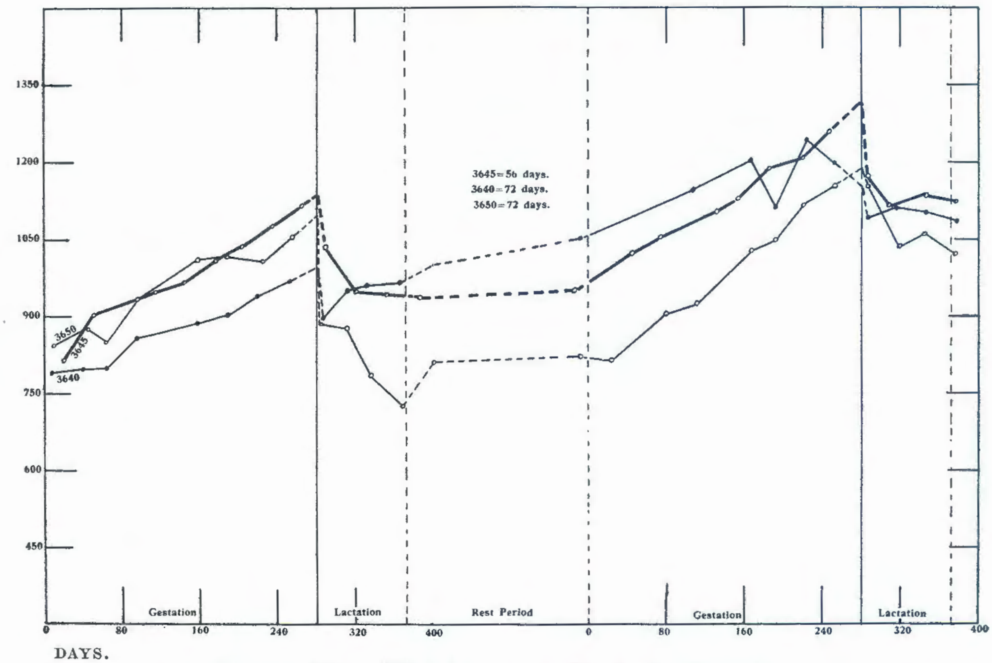


Graph V.—Weights of Animals in Pounds.

History.

No. of animal............	No. 3643.	No. 3655.	No. 3640.	No. 3650.	No. 3645. (control.)
Date experimental ration began, i.e. beginning first gestation...............	2.9.30	1.9.30	9.9.30	28.8.30	29.10.30
Date of calving..........	27.5.31	24.5.31	2.6.31	1.6.31	19.7.31
End of lactation.........	27.8.31	24.8.31	2.9.31	1.9.31	19.10.31
End of rest period, i.e. beginning second lactation	18.12.31	19.11.31	13.11.31	not	14.12.31
Date of calving..........	22.9.32	25.8.32	21.8.32	pregnant	25.9.32
Date of conclusion of experiment..................	22.12.32	25.11.32	21.11.32	15.12.32	25.12.32

A graphic representation of the weights of (A) the animals on low calcium only, viz., Nos. 3643 and 3655, and (B) the animals Nos. 3640 and 3650 on low calcium and low magnesium, are given in Graphs V and VI respectively.



Graph VI.—Weights of Animals in Pounds.

Before comparing Graphs V and VI it must be noted that animal No. 3640 calved after the first gestation period, but dried off within a week. It is not surprising, therefore, that she remained in excellent condition until shortly before the end of the second gestation period when she began to lose weight. Still, after 3 months lactation, this animal finished almost on a par with the control, No. 3645. No. 3650 felt the drain of lactation severely in 1931, but for the rest nothing very significant is apparent from the charts, except perhaps that the second lactation period gradually increased the difference between No. 3650 and the control. The differences between No. 3643 and No. 3655 (Graph IV) are perhaps even less significant. It is true that these animals were lighter than the control, but such was the case practically from the beginning of the experiment, and only during the two lactation periods was the difference between the control on the one hand and the experimental animals on the other made significant. It seems, therefore, that the low calcium that existed in the rations of the animals in this experiment might have made itself felt in a longer lactation period but that for the rest of the experimental period it did not show significant effects upon the animals.

It is impossible to state definitely the effect of low or high magnesium upon the animals. Nos. 3643 and 3655 seem to have done slightly better on the whole, but generalizing would be dangerous without further proof. The effects of a calcium deficiency during lactation—the only time that such a deficiency was certain—undoubtedly masked the effect of magnesium. At all events whether high or low magnesium was present, the curves diverge during lactation, i.e. the period of acute Ca deficiency and show a tendency to converge gradually for the rest of the period.

It would be interesting to glance at the milk production of these four animals given in Table V and also at the Tables III and IV giving the intake of minerals in the food and the outgo in the milk.

Undoubtedly greater milk production by the four experimental animals made greater demands upon their systems than in the case of the control animal. Proof of this lies in the weight chart of No. 3655 during the first lactation period. She approached the control more closely than her mate but produced about the same quantity of milk as the control and well over 200 lb., i.e. more than 2 lb. a day less than her mate. During the second lactation period when a protein supplement was given, and incidentally the calcium intake more than doubled, although it remained still definitely less than the output in the milk, the differences of the effect of lactation upon the weight curve in the case of No. 3650 and No. 3640 was even less marked. No. 3640 produced about the same quantity of milk as the control and No. 3650 just over 2 lb. a day more. Both Nos. 3655 and 3643 had difficulty at calving the second time, went off their feed and were reported sick for several days. This additional setback must be borne in mind when the weight curves are studied.

That longer lactation periods would have made themselves felt and would have had marked effects upon the weights of the experimental animals, but that, for the rest of the experimental period, the low calcium in the ration had doubtful effects upon the animals, seems to be suggested by the weight charts of the animals and by a consideration of the intake and outgo of minerals during lactation. This is apparently a justifiable conclusion. Furthermore it is well to remember that soil eating could not be entirely eliminated from this experiment, and that the intake of calcium was, therefore, slightly more than that stated in Table II.

The results of the blood analyses for Ca and Mg of Nos. 3643, 3655 and 3645 and of Nos. 3640, 3650 and 3645 do not reveal anything significant.

Both calcium and magnesium remained remarkably constant throughout the experimental period. Apparently the calcium in the food was not sufficiently low to produce an effect upon blood calcium, while it is doubtful whether a daily intake of 11·1 gm. MgO could be regarded as insufficient for the requirements of cattle. In any case, the magnesium level of the blood remained remarkably constant throughout.

A comparison of the experiments so far considered, viz. low calcium with high and low magnesium respectively; low calcium and low phosphorus; and low phosphorus, is necessary at the present stage, and brings to light several salient factors.

It is difficult to see what rôle low calcium played in these experiments. The effects of low calcium and low phosphorus were not more detrimental to the animal than those of low phosphorus alone. The demand for phosphorus during milk production was higher than that for calcium and apparently the animals in the low calcium groups were able to meet that demand without serious loss of condition, while that in the phosphorus low group died indirectly of aphosphorosis. It seems that 11·1 gm. MgO were enough to meet the demands of the animals for that mineral. It is realized that the figure giving the intake of calcium in Tables II, III and IV is probably slightly lower than the actual intake; still it is thought that a serious calcium deficiency would be difficult to bring about except during lactation.

Practical aspects of this work upon low calcium and low phosphorus will be considered further on in the text.

Experiment IV.

Ration low in all minerals except P and Ca.

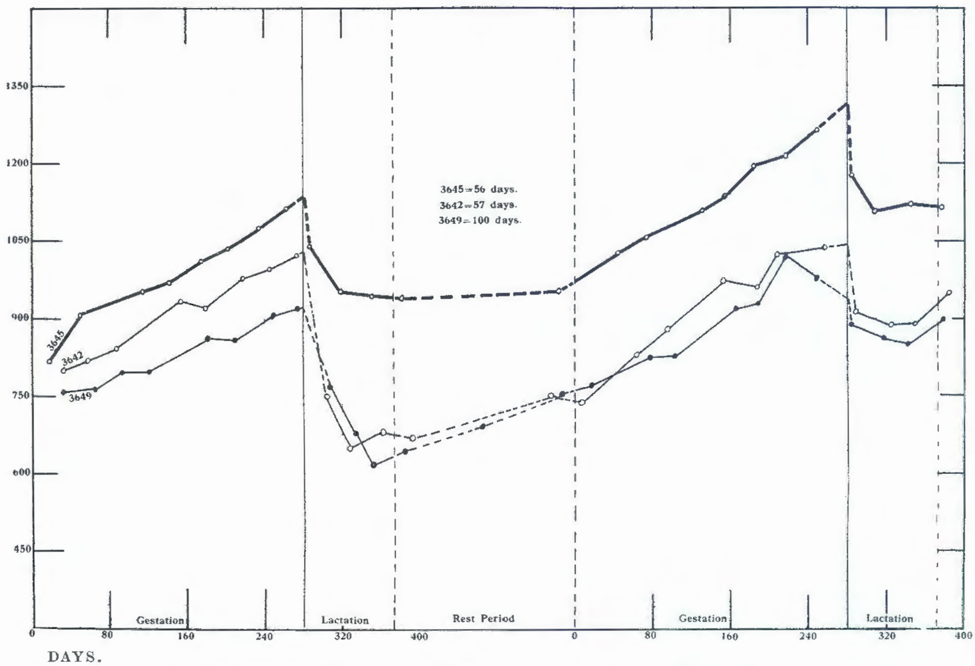
History.

No. of animal	No. 3642.	No. 3649.	No. 3645 (control).
Date of experimental ration began, i.e. beginning first gestation	15.9.30	21.8.30	29.10.30
Date of calving	10.6.31	12.5.31	19.7.31
End of lactation	10.9.31	12.8.31	19.10.31
End of rest period, i.e. beginning second lactation	6.11.31	20.11.31	14.12.31
Date of calving	16.8.32	25.8.32	25.9.32
Date of conclusion of experiment	16.11.32	25.11.32	25.12.32

Reference to Table II shows that the intake of minerals for the greater part of the experiment was as follows:—CaO 47·1 gm., MgO 11·1 gm., K_2O 29·3 gm., Na_2O 5·7 gm., P_2O_5 45·1 gm., Cl 6·7 gm., SO_3 12·9 gm. The ration is potentially alkaline with a decidedly positive earth-alkali-alkalinity.

The weight charts of the animals in this experiment, viz. Nos. 3642 and 3649 are given in Graph VII together with that of No. 3645.

Both these experimental animals were lighter at the beginning of the experiment than the control and both showed very remarkable drops in weight during the first lactation period, although they had



GRAPH VII.—Weights of Animals in Pounds.

kept condition quite well up to the time of calving. After that they remained in very poor condition throughout the experiment, were poor at calving and could ill afford a further drop in weight. They showed poor appetites for the first time during the first lactation period and repeated this behaviour during the second lactation period. On an average each consumed daily a lb. of the maize-fanko mixture less during both lactation periods than she did otherwise or than the control animal did. Food was refused eratically, all or practically all the food being refused approximately once a week during lactation. Apart from their poor condition the animals appeared listless most of the time and were reported stiff on several occasions.

The animals showed a decided improvement during the rest period, but it seems that gestation heavily taxed their powers of endurance, and that a change for the worse set in before the end of gestation. A second lactation period was just about as much as the animals could stand, although it must be noted that they gradually increased in weight towards the end of lactation, of which more anon.

Both animals produced approximately as much milk as the control as shown in Table V.

It is noteworthy that the milk flow rapidly decreased in both cases during the first lactation period, the animals giving only about a third of the first months' milk during the last month. As a matter of fact, the reason why it was decided to discontinue milking after

3 months in all the groups, was because Nos. 3642 and 3649 had practically ceased to produce milk at the end of that period and were very rapidly drying off. In both cases less than 2 lb. milk per day were produced during the last week against 24 lb. in the beginning. This is also the probable reason for the slight increase in weight during the latter part of the first lactation period. During the second lactation period milk production continued steadily for the full period and a glance at Tables III and IV giving the intake of minerals and their secretion in the milk, supplies the reason for the difference in this respect between first and second lactation.

Table III refers to the first lactation period when the animals were on a protein deficiency as well as a deficiency of certain minerals. Magnesium again, may probably be ruled out as the intake was 21·4 gm. and only 1·3 gm. secreted in the milk. It is difficult to state anything definite about potassium at this stage. The daily intakes of sodium and chlorine during the first lactation period were 5·7 and 6·7 gm. respectively, while the quantities secreted in the milk were respectively 4·8 and 6·6 gm. Both elements were dangerously low in the food and could not have met the demands of the animals for these minerals for both milk production and other requirements. Referring to Table IV it is seen that the position with regard to the intake of minerals had improved greatly. Magnesium and potassium with no or in any case only doubtful deficiency during the first lactation period is more or less unchanged but more than twice the sodium contained in the milk was supplied in the food while the change was not quite so favourable as regards chlorine.

However, the effect of an all round better supply of minerals during the second lactation period is reflected in the weight curves, the animals showing only a small initial drop due to milk production and actually increasing in weight during lactation. One is forced to conclude that with protein sufficiency the intake of minerals in the case of Nos. 3642 and 2649 was enough to justify a better level of nutrition than that which existed when the animals calved. Hence an increase in weight soon set in. The milk production was on a par with that of the control. Bearing in mind the marked and rapid decrease in milk production during the first lactation period and the fact that protein deficiency did not have as marked an effect on milk production in any of the other groups, one is forced to the conclusion that the low intake of minerals other than calcium and phosphorus was rapidly felt and effected a decrease in milk which ensured a more favourable belance of intake over outgo during the last month of lactation than during the first.

Two points stand out clearly. A deficiency in minerals other than phosphorus or calcium is not easily brought about as shown by the second lactation period when the intake was not very greatly in excess of the mineral content of the milk, but still milk production continued normally and the animals were gaining weight, i.e. the mineral intake supplied the demand for milk production and other physiological requirements. When such a deficiency is effected, however, as for instance during first lactation, milk flow is rapidly decreased and one is led to presume that the body reserves of these minerals are not extensive and are rapidly exhausted.

There can be no doubt, however, that animals Nos. 3642 and 3649 were adversely affected by the conditions of the experiment. Both compared unfavourably throughout the experiment with the control. Not only were they lighter in weight, but to the eye they were poorer in condition, listless, had a rough coat, and appeared abnormal. That either sodium or chlorine or both contributed their share to the detrimental effects of the rations, seems safe to assume, but it is doubtful whether these were the only operating factors. When the next experiment is considered this point will be referred to again.

There are no outstanding points in the results of the blood analyses. As could be anticipated blood phosphorus indicates sufficiency throughout the experiment. Apparently the levels of the other minerals in the blood are not appreciably affected by the proportions of the minerals present in the rations of the animals under discussion. The high potassium value in the blood of No. 3642 was noticed right from the beginning of the experiment and it remained so throughout.

Experiment. V.

Ration low in Sodium and Chlorine but adequate in Other Respects.

History.

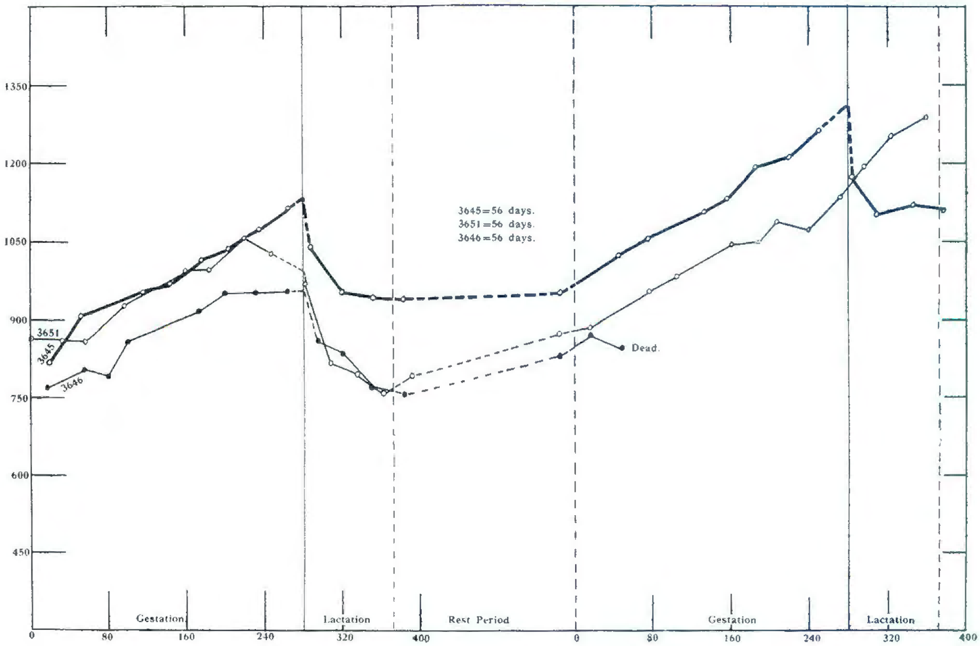
No. of animal	No. 3651.	No. 3646.	No. 3645 (control).
Date experimental ration began, i.e. beginning first lactation	9.9.30	21.8.30	29.10.30
Date of calving	4.6.31	21.5.31	19.7.31
End of lactation	4.9.31	21.8.31	19.10.31
End of rest period, i.e. beginning second lactation	not pregnant.	died 18.12.31 (impact).	14.12.31
Date of calving	—		25.9.32
Date of conclusion of experiment	30.11.32	—	25.12.32

Until May, 1932, the daily intake of Na and chlorine was 5·7 and 6·7 gm. respectively, whereas the other minerals were present in adequate quantities as in case of the control.

Graph VIII gives charts of the weights of animals Nos. 3651 and 3646 on a diet low in sodium and chlorine compared with the weight curve of the control No. 3645.

A glance at Graph VIII reveals the fact that comparisons can be made only until the end of the rest period. One of the experimental animals then died while the other did not conceive and therefore had no second calf. The weight curves of Nos. 3646 and 3651 suggest that detrimental effects of the experimental ration began to show about a month and a half before calving. The one animal actually dropped in weight while the other remained constant. Lactation accelerated the weight loss and it would be well therefore to glance at the milk production given in Table V at this stage.

Both the experimental animals started salivating excessively about 6 months after the beginning of the experiment, i.e. approximately three months before calving (9.2.31). This condition was



GRAPH VIII.—Weights of Animals in Pounds.

most noticeable during the hot hours of the day when saliva would be running freely for hours at a stretch, while breathing took the form of short, quick movements. In the case of animal No. 3646 this condition lasted at intervals of several days until the animal was removed to hospital on 30.11.31. At that stage the animal ceased eating and defecating, although up to that time she had not refused any of her food on a single occasion. The animal became worse, was given a purgative, without effect, and died 11 days afterwards of impaction of the omasum. This animal was a good milker and produced several hundred pounds milk more than either her companion or the control.

No. 3651 also began salivating profusely approximately 6 months after the beginning of the experiment. This condition was never so acute as in the case of No. 3646, and disappeared completely at the end of lactation. This animal did not conceive a second time and was discharged from the experiment towards the end of 1932 in prime condition.

There seems little doubt from the figures given in Table III, however, that these two animals suffered from a sodium chloride deficiency during lactation, if it is remembered that No. 3646 was actually secreting more sodium and chlorine in her milk than she was getting in her feed, while No. 3651 was secreting only just a little less. It is surprising that the effects of a sodium chloride deficiency were not more noticeable for, apart from profuse salivation and abnormal respiration, the one animal, at all events, behaved normally, while it is uncertain in how far the death of the other animal can be associated with the deficient diet. At all events this experiment is indicative of interesting results when working with rations very low in sodium and chlorine, while the possibility of such deficiency during periods of poor feeding, as for instance during droughts, should be kept in mind. This point will again be considered under a general discussion of the significance of mineral deficiencies. A comparison of Graph IX giving the weights of animals on a ration taken to be low in all minerals except Ca and P, with Graph X, leaves doubt about the ultimate effect of low Na and Cl in the ration. Na and Cl deficiency undoubtedly existed during lactation, but not with the same detrimental effect as in the last experiment, although the milk production of No. 3651 decreased rapidly, it is true. However, the point remains that apparently the bad effects of the experimental conditions in Experiment IV were not due to Na and Cl deficiency only or alternately other conditions in Experiment V, e.g. abundant K, partly masked the effects of low Na and Cl. It seems necessary to elucidate this point by conducting an experiment with cattle on low Na and Cl with low K and high K, respectively.

The blood analysis for sodium was without significance, the experimental animal showing figures that were no higher than those of the control. In the case of chlorine, especially during the period of acute deficiency, i.e. during the latter portion of the first gestation period and the whole of the lactation period a decided drop was shown as Graph IX suggests. It seems that low chlorine in the ration might be reflected as low chlorine in the blood. Such a condition seems natural if it is remembered that a low chlorine intake results in decreased elimination of chlorine via the kidneys—a condition probably associated with a lower chlorine level in the blood.

Experiment VI.

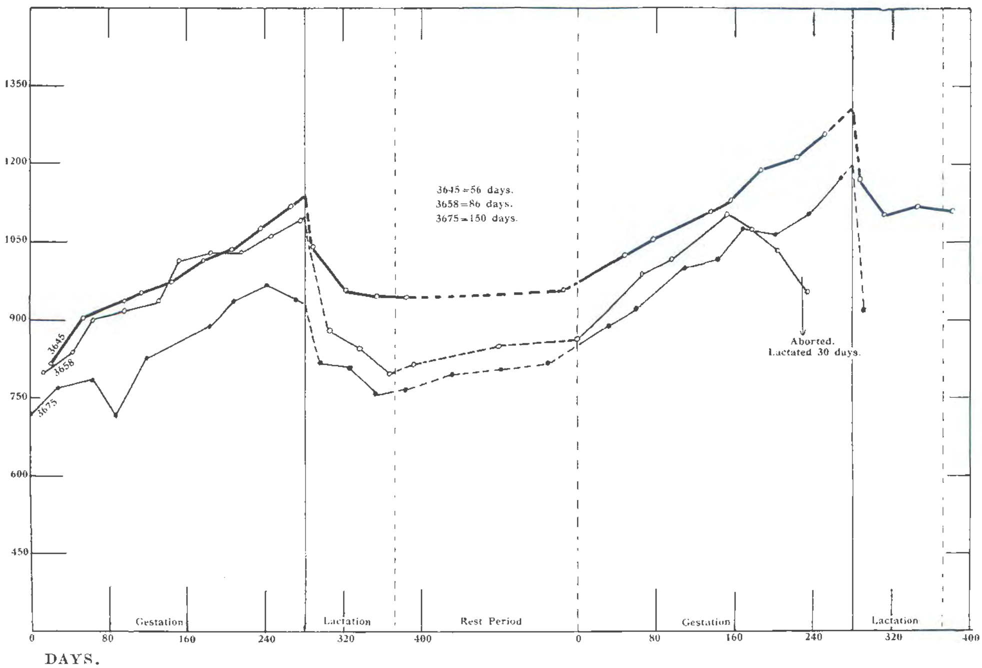
Ration low in Chlorine but adequate in Other Respects.

History.

No. of animal	No. 3658.	No. 3675.	No. 3645 (control).
Date experimental ration began, i.e. beginning of first gestation	3.9.30	12.8.30	29.10.30
Date of calving	7.6.31	12.5.31	19.7.31
End of lactation	7.9.31	12.8.31	19.10.31
End of rest period, i.e. beginning of second gestation	—	9.1.32	14.12.31
Date of calving	—	11.10.32	25.9.32
Date of conclusion of experiment	died 19.8.32 (T.B.)	died 29.10.32 (peritonitis.)	31.12.32

The daily chlorine intake was 6·7 gm. against 57·4 gm. in case of the control.

The weight curves of the experimental animals Nos. 3658 and 3675 together with that of the control are given in Graph IX.



GRAPH IX.—Weight of Animals in Pounds.

The milk production of the two experimental animals and of the control is given in Table V, while the intake of minerals and the outgo in the milk are given in Tables III and IV.

Both experimental animals actually secreted more chlorine in their milk during the first lactation period than that contained in the food—a condition which must have affected the animals adversely. It is also noticed, however, that the experimental animals were heavier milkers than the control, each having produced at least 3 lb. of milk more daily. These two groups, viz. chlorine deficiency and heavy milk production, must be borne in mind when viewing the greater decrease in weight of Nos. 3658 and 3675 during lactation than of No. 3645. Unfortunately both animals lived only for a short while after calving the second time; No. 3675 died of peritonitis after puncture of the uterus, while No. 3658 had to be destroyed on account of tuberculosis infection. Still the fact remains that, apart from lactation when, with greater secretion of chlorine in the milk than the intake of this constituent in the food, it is doubted how far the low chlorine of the ration had any bearing upon the course of the experiment. The rate of increase of weight of Nos. 3675 and 3658 agrees closely with that of the control, although the latter was and remained a heavier animal than No. 3675. No clinical symptoms were noticed in either animal during the experiment, food consumption was normal, and the animals behaved normally in all respects.

The results of the blood analyses for chlorine seem to confirm the findings in regard to the chlorine level of the blood made in the last experiment, viz., that low chlorine in the ration is associated with low chlorine in the blood.

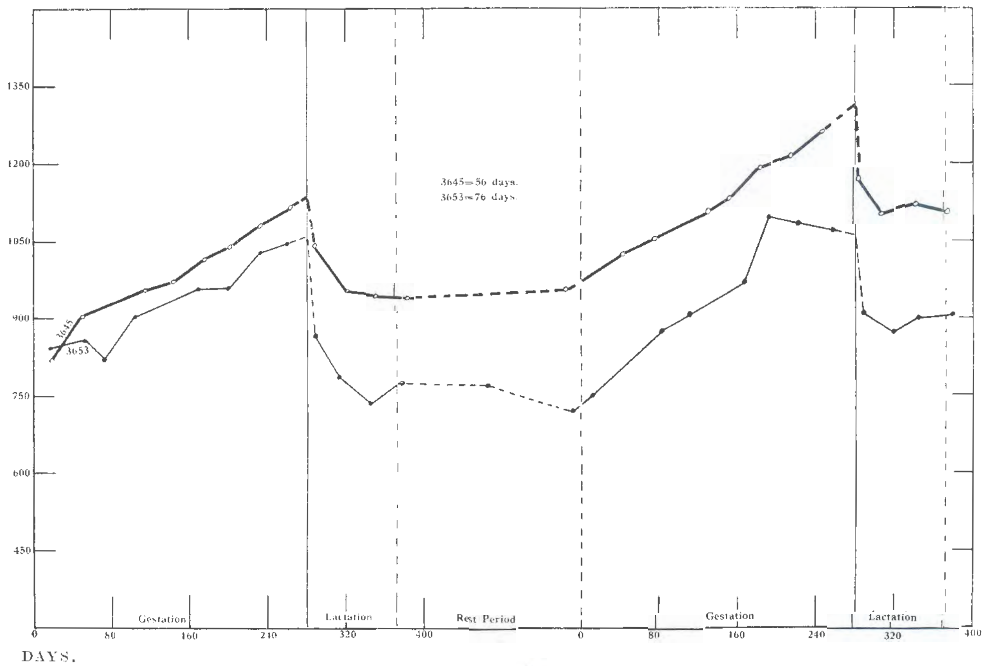
Summarizing the details of this experiment, it cannot be said that low chlorine, such as it was, affected the animals very adversely. Growth was satisfactory except during lactation. The average daily milk production showed a greater loss of Cl in the milk than that contained in the food, but both animals produced only about 12 lb. milk daily during the latter part of lactation, or in other words, less chlorine was secreted than was actually contained in the food. Apparently even a very low Cl intake did not have a marked effect upon the animals in this experiment taken generally.

Experiment VII.

Ration low in Na but adequate in Other Respects.

History.

No. of animal	No. 3672.	No. 3653.	No. 3645 (control).
Date experimental ration began, i.e. beginning of first gestation	20.8.30	26.8.30	29.10.30
Date of calving	10.5.31	24.5.31	19.7.31
End of lactation	10.8.31	24.8.31	19.10.31
End of rest period, i.e. beginning of second gestation	13.11.31	8.11.31	14.12.31
Date of calving	—	18.8.32	25.9.32
Date of conclusion of experiment	discharged 16.5.32 (I.B.)	30.11.32	31.12.32



Graph X.—Weight of Animals in Pounds.

The Na intake of the two bovines No. 3672 and No. 3652 was 5·7 gm. as compared with 18·9 gm. in case of the control.

The weights of animal No. 3653 is given in Graph X.

As animal No. 3672 was severely infected with tuberculosis, and showed many lesions on the post-mortem table, she will not be considered in the discussion of this experiment.

The milk production is given in Table V, while details of the difference between the intake of sodium and outgo in the milk are given in Tables III and IV.

It is evident that No. 3653 was a much heavier milker than the control, having produced during the first lactation period 2,127 lb. milk as against 1,446 lb. by the control. Furthermore, the outgo of sodium in the milk during lactation was definitely greater than the intake in the food. However, during both the first gestation and portion of the second gestation periods the animal did well, increasing in weight. Towards the end of the second gestation period, however, No. 3653 began to lose weight, which continued until after calving.

Considering the greater milk production of No. 3653 when compared with No. 3645, it is difficult to gauge the effect of low sodium in the ration. During lactation low sodium undoubtedly had some effect upon the animal as the excess of outgo over intake had to be provided for from the body reserves. The animal went off her feed on several occasions, appeared listless and lay down most of the time about a month before giving birth to her first calf. During the second gestation period she ate well and appeared normal throughout. It does seem probable, however, that towards the end of gestation the sodium deficiency began to be felt, if weight decrease is a criterion at all.

The blood analyses for sodium shows no outstanding difference between the sodium level in the blood of the control compared with that of the experimental animal.

The practical significance of low sodium in the diet of growing bovines is doubtful. Whether it is possible to obtain a ration sufficiently low in sodium to make itself felt, is also doubtful, except during lactation. It is remarkable that a ration containing only 5·7 gm. sodium daily could produce a normal increase in weight until lactation, and again afterwards, when lactation ceased, without causing more devastating effects than appeared in bovine No. 3653 in the experiment under review. However, it is to be admitted that the course of the experiment was not quite normal. Milk production was reduced during the first lactation period from 33 lb. daily during the first month to about 15 lb., which, incidentally, meant that during the latter part of lactation slightly more sodium was contained in the food than in the milk. On the other hand, the converse was the case for the first two months of lactation, and the animal lost heavily in weight. The second gestation period was not uneventful and the drop in weight towards the end shows that the strain of gestation began to be felt. During the second lactation period, however, the animal showed almost complete recuperation, at all events a great improvement, and a glance at Table IV reveals that the sodium intake was about 1½ times the quantity secreted in the milk. Milk production was very high—the highest of all the animals—but in spite of this the animal actually gained in weight. It appears that, although 5·7 gm. Na_2O was insufficient for the requirements of a 2-gallon cow during lactation and during the latter part of gestation, 15·5 gm. was definitely enough for a 3-gallon cow.

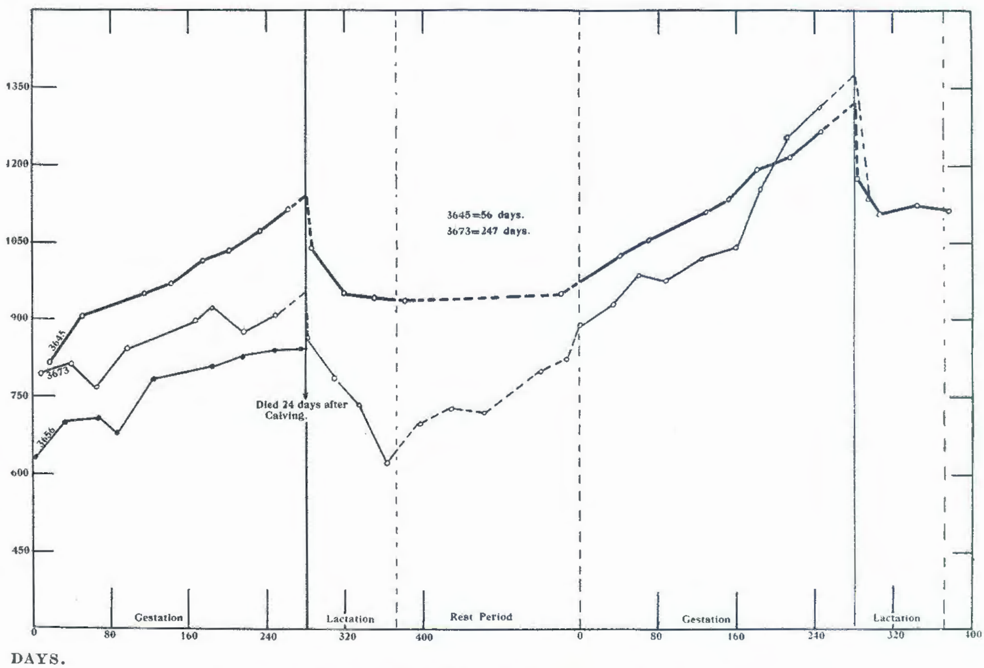
Experiment VIII.

Ration low in K, but adequate in Other Respects.

History.

No. of animal	No. 3656.	No. 3673.	No. 3645 (control).
Date experimental ration began, i.e. beginning of first gestation	19.8.30	29.8.30	29.10.30
Date of calving	8.5.31	5.6.31	19.7.31
End of lactation	Died 1.6.31 (metritis)	5.9.31	19.10.31
End of rest period, i.e. beginning of second gestation	—	29.4.32	14.12.31
Date of calving	—	6.2.33	25.9.32
Date of conclusion of experiment	—	6.5.33	25.9.32

From Table II it is evident that the daily potassium intake was approximately 30 gm. while the rest of the minerals contained in the ration was the same as those of the control animal No. 3645.



Graph XI.—Weight of Animals in Pounds.

The weight curves of No. 3656 and 3673 together with that of the control are given in Graph XI.

One of the experimental animals, viz. No. 3656, died of metritis 21 days after giving birth to a calf, while No. 3673 lasted the full period of the experiment, but with the longest rest period, viz., 247, days. This animal showed an appreciable drop in weight during the first lactation period, but improved in condition immediately afterwards until the second lactation began. Taking the weight curve as a whole, the only outstanding point is the great loss of weight during the first lactation period. After calving this animal suffered from mastitis, was removed to and treated in hospital for a considerable time. Hence it is difficult to judge the cause of the drop in weight correctly with three complicated factors, viz. low potassium, low protein and mastitis. During the second lactation, when the first two factors were absent, the response of the animal was quite normal compared with the control. At all events it appears that there was no deficiency present.

A glance at Tables III and IV, giving the intake in the food and the outgo in the milk of potassium during both lactation periods, and at Table V, giving milk production, confirms the tentative suggestion made by the weight curve, viz. that low potassium was probably not a serious factor to contend with in this experiment. Only about half of the potassium content of the food during both lactations was secreted in the milk. While a definite conclusion as regards the sufficiency or otherwise of potassium in the ration of the experiment under discussion cannot be drawn, there is no presentable proof for believing that potassium was deficient.

On the whole the potassium level of the blood of No. 3673 is slightly higher than those of the control. Whether these high values are significant, it is difficult to say, for the normal variation of K in blood is considerable. This point about the relation between the potassium in the food and that in the blood must be left in abeyance until more information is forthcoming.

Experiment IX.

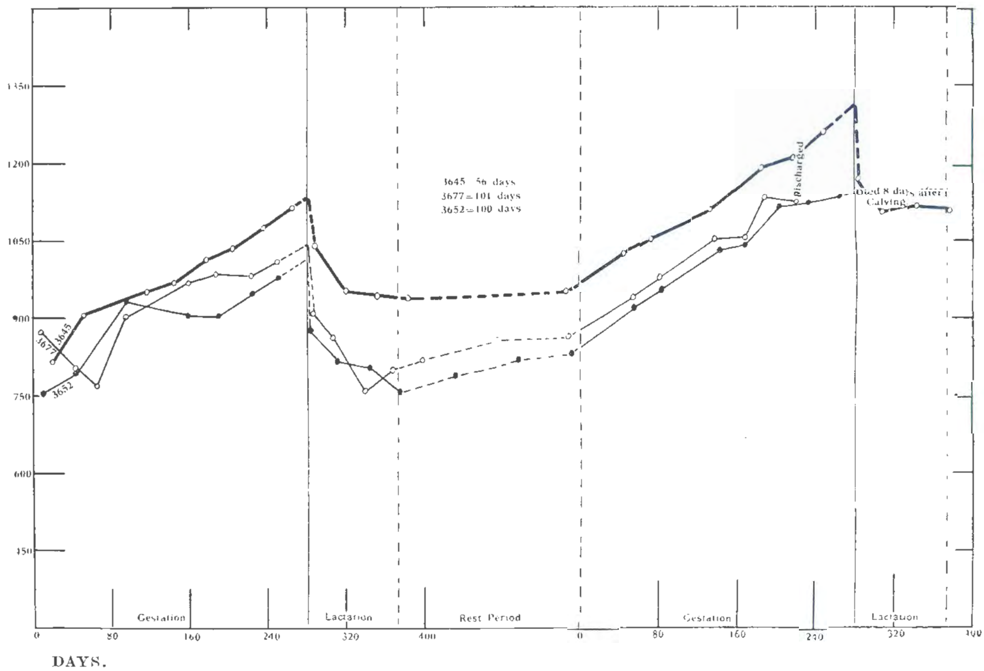
Sufficiency of all Minerals plus a Supplement of Potassium Iodide.

History.

No. of animal	No. 3677.	No. 3652.	No. 3645 (control).
Date experimental ration began, i.e. beginning of first gestation	3.9.30	2.9.30	29.10.30
Date of calving	2.6.31	2.6.31	19.7.31
End of lactation	2.9.31	2.9.31	19.10.31
End of rest period, i.e. beginning of second gestation	12.12.31	11.12.31	14.12.31
Date of calving	19.9.32	10.9.32	25.9.32
Date of conclusion of experiment	19.12.32	died 18.9.32 (peritonitis and metritis)	25.12.32

The two animals Nos. 3652 and 3677 in this experiment were on the same ration as the control, but received in addition a supplement of 0·1 gm. KI daily. Both animals remained normal, and ate well. One was discharged towards the end of the experiment as a suspicious case of tuberculosis, while the other gave birth to twins, retained her afterbirth and died of metritis 28 days afterwards.

The weight curves of the animals in this experiment are given below in Graph XII together with that of the control No. 3645.



GRAPH XII.—Weight of Animals in Pounds.

Neither from daily observations of the animals nor from the weight curves were any beneficial effects of potassium iodide administration noticeable. The experimental animals were not as heavy as the control, but the rate of increase or decrease was never markedly different. The milk production is given in Table V.

The milk production of the experimental animals was approximately the same as that of the control. Both lost more weight during lactation than the control, but at the beginning of the second gestation period the difference in weight of the experimental animals compared with that of the control was about the same as at the beginning of lactation, and remained practically so until the end of the experiment.

No marked beneficial effects of the iodine in the ration were noticed, nor can it be said that the iodine showed harmful effects.

The milk of both experimental cows contained, as was anticipated and has often been shown (Crichton, 1930), considerably more iodine than that of the control. The following figures give an indication of the results obtained.

Iodine in daily milk of No. 3677 varied from 39 to 99 γ per 100 c.c., while that in the milk of No. 3645 receiving no KI in its feed showed an average value of $7 \cdot 2$ γ ($5 \cdot 6$–$9 \cdot 2$).

No practical benefit of iodine feeding has been observed in this experiment. Perhaps a larger experiment carried out under field conditions to make differences in milk, production, reproduction, keeping conditions, etc., significant, would be a fairer test of the beneficial effect or otherwise of iodine feeding than the one reported on here.

V. GENERAL DISCUSSION OF EXPERIMENTS AND COMPARISON OF THE RESULTS OBTAINED.

It is undoubtedly difficult to assign correct values to the rôle of the respective minerals in nutrition, in the light of the results of the foregoing experiments. A number of salient points have been brought out by this investigation, however, and it is proposed to deal in this discussion with such factors and to compare the results of the experiments in a general way.

On the whole the results of individual experiments, with few exceptions, have been neither decidedly positive nor negative. This fact is most remarkable if Table II, on page 570, be looked at carefully. The table reveals the fact often repeated in this report that, with the single exception of magnesium, the intake of the minerals intended to be deficient in any particular experiment, was remarkably low. As a matter of fact, the intake was so low that, with the current conception that only a small proportion of minerals present in an ordinary ration (Crichton states 15–20 per cent.) is absorbed, it is remarkable that the animals could produce milk at all. In most cases they required daily approximately as much, and in several cases more, of the particular mineral (Ca, P, Na, K and Cl) than the ration contained of that particular constituent. Yet milk production continued under those conditions for 90 days, with, it is true, in some cases bad effects upon the animal, but no fatal effects except in the phosphorus deficient group or complete cessation of milk flow except perhaps in Nos. 3642 and 3649, when an attempt was made to make all minerals, except Ca and P, as low as possible. Drastic effects of the mineral intakes during lactation upon the animals would be anticipated from the fact that in all cases except magnesium, the total daily intake of a particular mineral was hardly different from that secreted in the milk during the same period apart from other physiological requirements of the animals.

At this stage it is necessary to study Tables III, IV and V carefully.

TABLE V.

Monthly Milk Yield in Pounds.

D.O.B. No.	Group.	First Lactation, 1931. Month. 1st.	2nd.	3rd.	Average per day in lb.	Second Lactation, 1932. Month. 1st.	2nd.	3rd.	Average per day in lb.
3641	I. Low Ca and P.....	733·7	654·1	469·5	21	—	—	—	—
3648		452·3	438·6	439·7	15	—	—	—	—
3659	II. Low P............	770·6	676·2	577·3	22	817·6	—	—	—
3643	IIIA. Low Ca..........	654·4	583·3	505·4	19	771·7	703·2	652·6	24
3655		542·7	505·0	458·2	17	798·1	845·7	790·1	27
3640	IIIB. Low Ca..........	—	—	—	—	672·9	738·4	661·7	23
3650	Low Mg..........	621·0	682·6	526·2	20	858·1	766·9	736·1	26
3642	IV. All min. low except Ca and P.	714·8	419·1	240·7	15	719·7	692·0	617·3	22
3649		663·5	470·3	254·1	15	730·9	660·4	659·6	23
3651	V. Low NaCl.........	554·4	426·5	306·9	14	—	—	—	—
3646		684·4	669·6	556·3	21	—	—	—	—
3658	VI. Low Cl...........	703·2	649·7	492·1	20	487·8	—	—	—
3675		715·5	557·3	483·0	19	—	—	—	—
3653	VII. Low Na..........	1010·9	645·3	470·8	22	933·8	929·2	853·7	30
3656	VIII. Low K...........	—	—	—	—	—	—	—	—
3673		536·1	492·9	271·9	14	—	—	—	—
3677	IX. All min. sufficiency + KI	465·4	634·6	482·2	16	601·4	413·0	488·0	17
3652		512·5	428·8	382·1	15	—	—	—	—
3645	X. All min. sufficiency..	500·4	498·5	447·3	16	746·1	698·7	611·2	23

(*a*) Na, K, Cl and Mg.

Omitting calcium and phosphorus for the time being and magnesium entirely, as it seems very improbable that the effects of "low" magnesium were felt at any time, sodium, chlorine and potassium are left to be dealt with. Undoubtedly a deficiency of sodium and of chlorine existed during the first part of the first lactation period. The result invariably was that milk production decreased until the quantity of the mineral secreted in the milk was definitely less than that contained in the food, although usually not much less. During the second lactation period the intake was always more than the milk content of any one of these three constituents, with the result that the lactating animals which lasted the full period, actually showed improvement in condition, or as in the case of the K low animal, which was in excellent condition at calving, showed no abnormal effect.

If Experiments V, VI, VIII and IX be reviewed, several points stand out which are worth recording: Animals Nos. 3642 and 3649, on a ration containing about 30 gm. K_2O, 5·8 gm. Na_2O, 7·3 gm. Cl for 20 months which included two gestation periods and one lactation, remained in very poor condition throughout the experiment and could easily be selected at any stage as the poorest group. The combined effect of low Na, K and Cl in the ration affected the animals adversely and resulted in permanent loss of condition and poor appetite. During the second lactation, when these animals never produced less than 2 gallons milk daily, they actually improved in condition and gained in weight on a ration containing 30 gm. K_2O, 15·5 Na_2O, 13·8 gm. Cl, while the secretion of these minerals in their milk was as follows: K_2O 24 gm.; Na_2O 7 gm.; Cl 10 gm. Animal No. 3653 on a sodium low ration fared similarly. 5·8 gm. Na_2O during the first 2 months of the experiment with its two gestation and one 90-day lactation periods, was apparently insufficient to meet the demands of the animal, but when this quantity was increased to 15·5 gm. Na_2O during second lactation, the animal easily stood the strain of producing over 3 gallons of milk daily. It must be noted that the daily milk contained 9·6 gm. Na_2O. In other words, No. 3652 secreted two-thirds of the total intake of sodium in her milk for 90 days without apparent ill effects upon her system. Cow No. 3673 receiving daily about 30 gm. K_2O during the first 20 months of the experiment with two gestation periods, one lactation period, during 50 days of which this animal suffered severely from mastitis which was followed by a long rest period, apparently did not suffer from a potassium deficiency. During second lactation, when this animal gave over 2 gallons of milk daily, containing 22 gm. K_2O, she remained in good condition throughout, and was apparently not abnormally affected by lactation. The conclusion seems justified that No. 3673 required during growth and pregnancy less than 30 gm. K_2O daily, while during a 90-day lactation period of over 2 gallons daily, 38 gm. K_2O were ample in spite of 22 gm. K_2O actually being secreted in the milk. Unfortunately no further light is thrown on the rôle of chlorine, as the remaining animal in the experiment after the first lactation period did not become pregnant. Tentatively it may be stated, in the absence of further data, that 7 gm. chlorine in the daily ration appears to have been on the low side during first gestation, when the animals were still actively growing, was definitely deficient during lactation, secretion in milk being greater than intake, but cannot be said to have had further ill effects. Judging from the effects of low sodium in the ration, one would be inclined to believe that during lactation at least one and a third times the amount of chlorine contained in the milk should be supplied in the food. Passing to the animals Nos. 3646 and 3651 on low sodium chloride it is perhaps strange that these animals did well on the whole in spite of having in addition to low sodium, with its detrimental effects upon No. 3653, also low chlorine. The only difference between the rations of No. 3653 on the one hand and Nos. 3646 and 3651 on the other is, that the ration of No. 3653 was potentially more acid, due to the presence of chlorine. The additional potential acidity was equivalent to 1620 c.c. normal solution, but from the available data it is impossible to judge this effect at all correctly. It can only be said that low sodium was detrimental, whereas low sodium in addition to low chlorine was not; and thirdly that low sodium, low chlorine, low potassium again produced detrimental effects. It appears that the relation of these three constituents to one another is important and need further consideration.

Applying the information gained in these experiments with regard to low K, Na and chlorine in a ration to possible deficiencies in practice the following points are brought out:—

(1) Potassium deficiency, which cannot be said to have been brought about in Experiment VIII will probably never be present in two-gallon capacity lactating cows on pasture. Even ·4 per cent. K_2O in pasture, which is much lower than the usual figure, would supply about twice as much potassium as that contained in the potassium low ration.

(2) The chlorine content of the rations in Experiments V and VI was much lower than the intake of cows on very poor pasture (·15 per cent. chlorine). As a matter of fact, a 1,000 lb. cow on such pasture would probably ingest about 3 times as much chlorine as the animals in the chlorine low rations of this investigation.

(3) The sodium intake of the animals in Experiment VII on low sodium, was not particularly low. Mature South African pastures often contain as little as ·015 per cent. Na_2O under which conditions a 1,000 lb. cow would ingest only about as much sodium as that contained in the sodium low ration or, in other words, only about as much as she actually required for the production of 2 gallons of milk. Sodium deficiency in South African pastures at certain times of the year, when only fully grown mature and often old grass is available, is well worth the serious attention of investigators in this field.

(4) The combined effect of low Na, Cl and K was detrimental to the health of the animals, but there is little danger of procuring such an extremely low intake of these three constituents in animals on natural grazing.

(5) It is tentatively suggested that two-gallon lactating cows require daily, as a minimum, one and a half times the quantities of easily available Na and Cl secreted in the milk, i.e. about 15 gm. Na_2O and about 13 gm. Cl, while an intake of 38 gm. K_2O is sufficient to provide for the secretion of over 21 gm. K_2O in the milk without deleterious effects upon the cow.

(*b*) Calcium and Phosphorus.

With regard to Experiments I, II, III and IV on the rôle of P and Ca, the position is more clear. The often observed fact that low phosphorus in a ration brings about stywesiekte, poor condition, low inorganic phosphorus in the blood, and general unthriftiness, has been confirmed both in Experiment I and II. The latter experiment was a straightforward P deficiency, while the animals in the former were subject to low calcium in addition to low phosphorus. A consideration of Experiments III and IV indicates that the animals in both experiments withstood the low calcium quite well. On the other hand, Table III indicates that calcium deficiency was acute during both lactation periods. The animals, as already stated, ingested a certain amount of soil, so that the intake of calcium was probably higher than that given in Table II. However, apparently Ca deficiency was practically without effect upon the animals and the only possible conclusion seems to be that the intake of Ca with the soil must have increased the total intake of Ca very considerably, as it seems very improbable that the animals in Experiment III on low Ca could have continued to secrete in their milk, without more marked effect on their bodies, about twice the quantity of calcium that they were getting in their food. Clinical symptoms of calcium deficiency were not noticed in this investigation, and it is feared that reliable conclusions about the calcium requirements of cattle cannot be drawn until additional data have been obtained from an experiment now under consideration on the rôle of the Ca, P complex in the nutrition of bovines.

As suggested by a study of the phosphorus intake and outgo of Nos. 3641, 3648 and 3659 in Tables III and IV, by clinical symptoms of aphosphorosis in the course of the experiment, and by low inorganic phosphorus in the blood, phosphorus deficiency was acute for the greater part of the experiment. Expressed as P_2O_5 the demand for phosphorus during lactation is greater than that of any other mineral, and unfortunately, varies greatly from season to season.

It may be pointed out here that Crichton (1931) considers that one of the authors (A. I. M.) is of the opinion that inorganic phosphorus in the blood limits milk production, but that he erroneously attributed that view to the author concerned. It has been pointed out time and again from this Institute, that phosphorus deficiency limits milk production and is also *associated with* low inorganic phosphorus in the blood. But it certainly would be illogical and purely speculative for anyone to conclude that therefore inorganic phosphorus in the blood limits production. Under South African conditions, at the best of times, pasture will not usually contain more than ·45 per cent. P_2O_5 for any length of time. In such circumstances 25 lb. pasture (on dry basis) would contain about 50 gm. P_2O_5, which would hardly meet the requirements of a 2-gallon cow. It may safely be said that without drastic pasture improvement there is little hope of getting a daily milk production for any length of time of 2 gallons from cows on pasture only. Unfortunately low protein in such pasture would be an additional limiting factor for the production of 2 gallons milk. Phosphorus supply is undoubtedly a problem that has to be contended with under systems of milk production under ranching conditions.

(*c*) Reproduction.

Before concluding, it is necessary to review reproduction in this investigation. In Table VI below the calving chart of the animals is given.

TABLE VI.

First Calving, 1931.							*Second Calving*, 1932.				
D.O.B. of Cow.	D.O.B. of Calf.	Experiment.	Gestation Period. Days.	Birth Wt. of Calf.	Remarks Calves.	Remarks Cows.	D.O.B. of Calf.	Gestation Period. Days.	Birth Wt. of Calf.	Remarks Calves.	Remarks Cows.
3641	4543	Low Ca and P.	272	50	Normal..........	—	5212	284	78	Normal.	23.9.32 killed in extremis.
3648	4540		275	68	Normal..........	—	5265	281	87	Normal	1.3.33 died sequel to shock to fall.
3659	4552	Low P....	279	63	Blind and strong	—	5207	282	87	Blind but strong	4.10.32 died of P deficiency.
3643	4535	Low Ca...	267	65	Blind and weak..	—	5236	278	78	Normal	23.12.32 dismissed.
3655	4533	High Mg..	265	50	Normal...........	—	5209	280	90	Normal	7.12.32 killed for skeleton.
3640	—	Low Ca and Mg.	266	53	*Lived few hours, blind	—	5206	281	92	Normal	6.12.32 killed for skeleton.
3650	4536		277	45	Blind............	—	5214	284	88	Normal	5.12.32 dismissed.
3642	4548	All min. def. except Ca and P.	268	67	Unable to get up	—	5203	283	64	Normal	— collected skeleton.
3649	4529		264	46	Blind and weak..	—	5208	278	81	Normal	26.11.32 dismissed.
3651	4541	Low Na and Cl.	268	68	Unable to get up	—	—	—	—	—	— sterile, dismissed.
3646	4531		273	44	Weak, died 1 day old	—	—	—	—	—	8.12.31 died.
3658	4547	Low Cl....	277	63	Blind............	—	—	—	—	—	19.8.30 killed o/a T.B.
3675	4528		270	69	Unable to get up	—	5240	274	89	Normal	29.10.32 died of peritonitis.
3653	4534	Low Na...	271	58	Unable to get up	—	5204	283	76	Normal	20.11.32 dismissed.
3673	4546	Low K....	280	50	Blind............	—	5296	284	78	Normal	6.5.33 dismissed.
3656	—		262	46	*Aborted........	—	—	—	—	—	— died, peritonitis.
3677	4538	All min. sufficiency, plus KI	272	67	Normal..........	—	5232	280	82	Normal	— dismissed, T.B.
3652	4539		273	61	Blind............	—	5226 5227	273	51 65	Normal Normal	—
3645	—	All min, sufficiency	263	55	*Aborted, normally developed	—	5237	284	100	Normal	27.12.32 dismissed.

A glance at Table VI reveals the fact that in 1931 calving was abnormal. Weak and blind calves were the rule, and almost 50 per cent. of the calf crop was blind. The vitality of the calves was low in practically all cases. It seems that a factor present in all the experiments was responsible for poor reproduction, and it is for this reason that 5 lb. ensilage were added to the basal ration of each animal in 1932, i.e. about 6 months before second calving period was due. The increase of minerals was negligible as shown in Table II, but subsequent calving was a complete success.

In the light of this work and of that of Hart, Hadley and Humphrey (1932), where similar results were obtained with a basal ration consisting primarily of wheat products, it appears that the birth of abnormal calves in this experiment should be associated with an inherent deficiency in the ration, such as poor quality protein or perhaps vitamin A. 5 lb. of ensilage containing 80 per cent. water, can hardly be said to add much " quantity " of any food constituents to the ration, while it is rich in vitamins, as is all green feed. The problem of poor reproduction must be left unsolved until the experiment now being conducted to elucidate this point has yielded some information, and it is taken for granted provisionally, especially when the two calving periods are compared, that abnormal calving in 1931 was not associated with any specific factor related to the mineral composition of the rations. Apparently the 5 lb. ensilage which, according to Table II, hardly increased the mineral content of the basal ration at all, contained the factor or factors which made calving in 1932 one hundred per cent. successful. No weak or abnormal calves were born, although the number of animals still alive to calve down was considerably less than in 1931.

VI. SUMMARY.

1. Data are presented on the requirements of growing and lactating cattle of Ca, P, Mg, Na, K, Cl and I.

2. The investigation lasted approximately 2½ years; the animals passed through 2 gestation periods and two lactation periods of 90 days each.

3. A pair of grade Friesland heifers was placed in each experiment on a basal ration of 3½ lb. hay, 10 lb. maize concentrates [crushed maize and/or maize endosperm (fanko)] and 20 gm. blood meal.

4. The mineral content of the basal ration was as follows: CaO 6·8 gm.; MgO 11·1 gm.; K_2O 29·3 gm.; Na_2O 5·7 gm.; P_2O_5 15·4 gm. and when crushed maize was eliminated 8·4 gm.; Cl 6·7 gm. and SO_3 12·9 gm. All the minerals were given as supplements daily, except Sundays, with the concentrates.

5. The animals were inspected daily for symptoms of deficiency, weights were registered monthly, food consumption checked and samples of blood drawn monthly for the determination of their mineral content.

6. The animals were kept over night under roof in feeding boxes in an open shed. During the day they were allowed to exercise in a paddock with concrete floor, except on some occasions when they were allowed into an adjoining paddock with a surface of sand.

7. 0·1 gm. potassium iodide had no visible effect upon the pair of bovines in this experiment.

8. It is provisionally suggested that 14 gm. Cl was enough to provide for the daily secretion of 2 gallons of milk and that this amount would also be enough for growth and gestation.

9. When one and a half times the quantity of sodium contained in 2 gallons of milk is supplied in the food, this is apparently enough for the normal production of such a quantity of milk, i.e. about 15 gm. Na_2O per day.

10. ·38 gm. of K_2O was enough for the production of 2 gallons of milk daily for 90 days without ill effects.

11. There is very little possibility of a K or a Cl deficiency when 2-gallon cows are run on pasture only.

12. The sodium content of a 1,000 lb. cow's ration of South African pasture ·015 per cent. Na_2O is often below that of the basal ration, which is deficient for the production of 2 gallons of milk daily.

13. It was impossible to produce clinical or other symptoms of acalcicosis. An explanation is offered tentatively.

14. Aphosphorosis—incipient and clinical—was easily produced on a ration both low and not so low in phosphorus.

15. Radiographs of selected bones of phosphorus and calcium deficient animals are presented.

16. A lactating animal's defence against mineral deficiency is decrease in milk production, the greatest decrease being noticeable when the deficiency is greatest, e.g. Experiment IV, low K, Na and Cl.

17. It is doubted whether low magnesium could possibly become a problem in an animal's diet. The basal diet composed of materials low in minerals contained at least 5 times the amount of magnesium secreted in 2 gallons milk.

18. The present study is being followed up by a study of the rôle of the Ca, P complex in the nutrition of cattle and by further studies on Na, K and chlorine low rations.

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