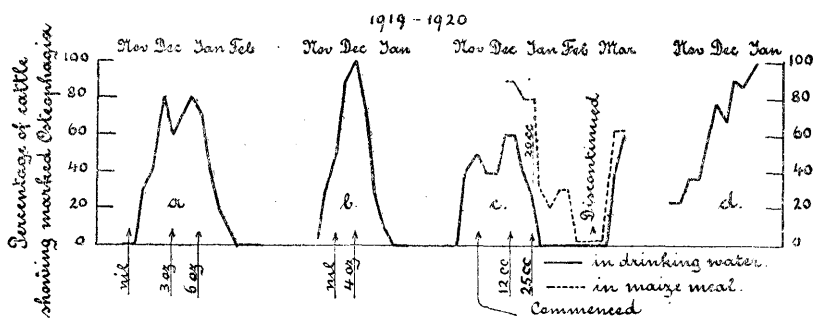
hydroxide, and potassium carbonate did nothing to alleviate osteophagia. This of course is quite in accord with expectation, since there is no shortage of calcium, magnesium, potassium, or iron in the natural vegetation, the analysis of which is so characterized by deficiency in phosphorus. Finely ground furnace cinders (60-mesh sieve), containing mixed minerals from the ash of coal and wood, are without effect.

Summarizing the data, then, in the light of the behaviour of control animals, other mineral salts and compounds poor in phosphorus are not capable of alleviating osteophagia. Of all the materials tested at various times, those rich in phosphorus have been found effective and those poor in phosphorus ineffective.

The data with various foodstuffs given as supplementary rations to the cattle may now be presented, but before doing so the tables representing administration of pure calcium phosphate, sodium phosphate, and phosphoric acid may be discussed.

CHART VI (APPENDIX TABLES 33 TO 38).



a. Sodium phosphate.
b. Calcium phosphate.
c. Phosphoric acid.
d. Hydrochloric acid controls.

INFLUENCE OF PHOSPHATE AS SUCH.

Pure precipitated calcium phosphate was compared with sodium phosphate in order to make quite sure that the base in combination with the phosphorus played no considerable part in the reduction of osteophagia, while phosphoric acid itself was given in order to eliminate the base altogether. As control to the phosphoric acid experiments, a batch of cattle were dosed with hydrochloric acid in order to take into account the possible influence of acidity as such.

The first series of trials represented in Appendix Tables 31, 32, and earlier part of 33, need not be charted, since the results were vitiated by the effect of the early summer rains upon the natural pasture. As the permanent controls show, the extent of osteophagia was rapidly diminishing at this time, and only the later dates need therefore be considered. Chart VI, plotted from Tables 33 to 38, shows the influence of sodium phosphate, calcium phosphate, and phosphoric acid at the time when the permanent controls showed rapidly increasing osteophagia.

It is at once apparent that the base in combination with the phosphorus is of little or no consequence. Sodium phosphate, calcium phosphate, and phosphoric acid all rapidly reduce osteophagia, and, as the hydrochloric acid controls show, the acidity of the phosphoric acid plays no part in the reduction.

In the sodium phosphate experiment (Table 33), it will be noted that after discontinuing the previous dosage on 11th November, the extent of osteophagia rose rapidly, and that by 15th December 80 per cent. of the cattle in the test showed craving for rotten bones. Upon then administering 3 oz. of sodium phosphate, equivalent to 17 grm. of phosphoric oxide (Table 10), per head per day, little immediate effect was produced, but on raising the dose to 6 oz. the disappearance of osteophagia was very rapid, falling from 70 per cent. to 40 per cent. in a week and disappearing altogether within a month.

In the phosphoric acid experiment (Table 36) one lot received the dose in the drinking water and the other lot in the form of a maize-meal paste. When administered in the drinking water at the rate of 10 c.c. to 12 c.c. (equivalent to 7 to 9 grm. phosphoric oxide) the effect was slow and uncertain, the extent of osteophagia fluctuating between 60 per cent. and 40 per cent. all through December. On doubling the quantity on 7th January, so giving the equivalent of about 18 grm. of phosphoric oxide, the effect was prompt. Osteophagia disappeared within a week and did not reappear so long as the dosing was continued. The experiment in which 20 c.c. to 25 c.c. phosphoric acid, equivalent to 15 grm. to 18 grm. of phosphoric oxide, was more accurately administered in the form of a maize paste, shows reduction of osteophagia from 100 per cent. to 20 per cent. in a month, and to zero in two months.

On discontinuing the phosphoric acid, both curves (Chart VI) shoot up at once, and osteophagia redevelops in 60 per cent. of the cattle (12 out of 20) within a fortnight.

In the experiment in which the phosphoric acid is combined with lime (Table 35) the osteophagia, rapidly acquired by simple veld grazing, was rapidly removed by administration of pure calcium phosphate. The 4 oz. given correspond to 45 grm. of phosphoric oxide, and although this is in insoluble form, the relatively large dose is relatively rapid in effect.

The hydrochloric acid controls, like the permanent controls of Chart II, show a steadily rising osteophagia curve throughout the same period (November to January) and indicate quite clearly the character of the veld, and the fact that mere acidity does not alleviate osteophagia.

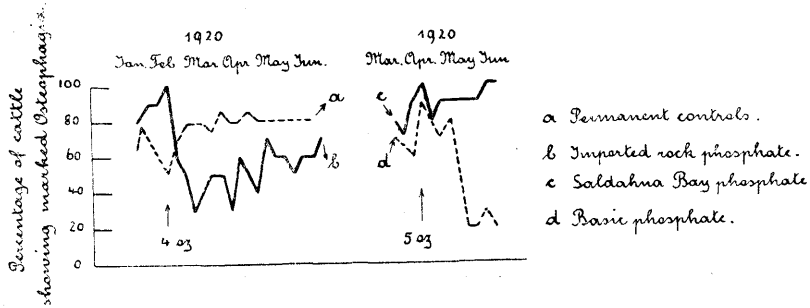
Appendix Table 34 (not charted) shows a second calcium phosphate experiment in which 5 oz. sufficed to reduce osteophagia in four out of ten cattle in a week. On then reducing the dose to 2 oz. craving continued to disappear in the ensuing fortnight, but reappeared in spasmodic fashion thereafter, and could not be excluded altogether until the dose was raised to 4 oz.

It may be mentioned that the experiments under consideration were carried out at a time when the extent of veld deficiency was not accurately known, and were not arranged with the object of comparing the " availability " of the compounds used. This question of " availability " of phosphorus contained in various substances is of considerable practical consequence, however, since it is generally

considered that bonemeal, or even bone-dust, is only utilized in digestion to the extent of about one-fifth, and a more readily available phosphate should therefore prove cheaper in practice. The whole question is under study at present, but it may be mentioned that experiments already carried out suggest that finely ground bonemeal is more readily utilized in digestion than is generally considered to be the case. The balance of cost and ease of administration may yet decide in favour of bonemeal for regular use, in spite of the greater availability of certain water-soluble phosphates.

Finely ground rock phosphate has a much lower availability than bonemeal, and " Saldahna Bay Phosphate " is practically useless. It is interesting to note, however, that even this latter phosphate, containing a very high proportion of aluminium and iron, and very refractory, is rendered more effective by conversion into so-called " basic phosphate." The accompanying Chart VII, plotted from Tables 39 and 40, compares rock phosphate, Saldahna Bay phosphate, and " basic phosphate " containing 16 per cent. phosphoric oxide in " citric-soluble " form.

CHART VII (APPENDIX TABLES 39 AND 40).



From this Chart VII, and Table 39, it may be noted that 4 oz. of imported rock phosphate containing 31 per cent. of phosphoric oxide (Table 10), or rather more than that present in 5 oz. of bonemeal, is not so effective as 4 oz. of bonemeal fed at about the same time of the year (Chart VI). Higher quantities have not yet been tried, but even if rock phosphate can be used, it will not be profitable unless effective in moderate amount. So long as its lower cost is offset by its lower availability, it will not replace bonemeal, since bonemeal is greedily eaten by the cattle whereas rock phosphate has to be mixed with other food or dosed by hand. Where, as in the case of cattle-ranching in the lamsiekte areas, it is not customary to supply supplementary foodstuffs, ease of administration of phosphatic allowance is an important factor.

The second pair of curves on the left of Chart VII, illustrates the difference between the refractory Saldanha Bay phosphate itself and the same phosphate after conversion to " citric-soluble " form. The dotted curve shows that 5 oz. of the treated phosphate containing 16 per cent. of phosphoric oxide, effected a marked reduction of osteophagia, whereas 5 oz. of the untreated phosphate is quite ineffective in spite of the fact that its phosphoric oxide content is much higher.

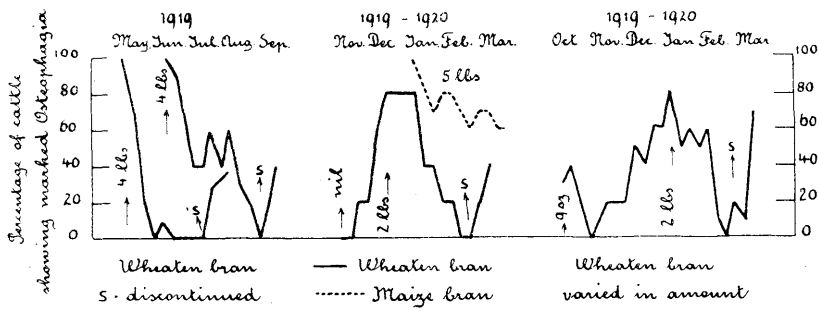
EFFECT OF FOODSTUFFS OF VARYING PHOSPHORUS CONTENT.

A number of feeding stuffs were fed at different times in order to ascertain the influence of supplementary feeding upon osteophagia. Of those utilized, the phosphorus-rich wheaten bran gave the most striking results, and the bran experiments may therefore be considered first.

Bran.—The following Chart IX plotted from Tables 41 to 45 illustrates the general behaviour with bran.

The two curves to the extreme left in Chart IX, and corresponding Table 44, indicate that 4 lb. of wheaten bran containing approximately 2 per cent. of phosphoric oxide (Table 10) is sufficient to reduce osteophagia rapidly in grazing cattle even during the months of May, June, and July, when the phosphoric oxide of the natural vegetation is at its lowest ebb. The 4-lb. ration of bran supplies approximately 0.08 lb. or 36 grm. of posphoric oxide, and this alone is sufficient

CHART IX (APPENDIX TABLES 41 TO 45).



to supply the ordinary requirements per 1,000 lb. live-weight of grazing cattle, irrespective of the moiety they receive from the grass. Only in the case of cows yielding milk is the phosphoric oxide of the grass then also needed. It is therefore not surprising that osteophagia should be rapidly reduced upon such a ration.

Tables 41 and 42, and the latter part of Table 43, show the influence of feeding 2 lb. of wheaten bran per head per day. This quantity is also indicated as sufficient to reduce osteophagia, although the rapidity of the fall shown in the curves of Chart IX is exaggerated by the fact that the cattle used had only recently developed craving and that in January and February the phosphoric oxide of the vegetation had not yet fallen to its minimum level. The 2 lb. of bran contained 18 grm. of phosphoric oxide, and this is shown as sufficient for the period of the year concerned. It would be sufficient even in June or July when the phosphoric oxide intake of the grazing cattle is down to about 11 grm. per " 8 lb. starch equivalent " of grass eaten, but at this time the rate of disappearance of osteophagia upon a 2 lb. ration would be slower.

Table 43, and the curve on the right of Chart IX indicates, however, that ½ lb of bran (8 to 9 oz.) per head per day is not sufficient to reduce osteophagia even in December and January. This small quantity, corresponding to about 9 grm. of phosphoric oxide, is not sufficient to supplement the natural phosphoric oxide of the grass, and the osteophagia curve rises much as it does in the controls, although its influence is shown by the retarded rate of

development of marked craving; the controls reaching 80 per cent. osteophagia by 1st December, as against the same figure on 5th January for the batch upon the small ration of bran. The earlier fall in osteophagia in October synchronizes with the natural fall due to the higher proportion of phosphoric oxide in the young grass, and has therefore no significance. The fall in osteophagia after raising the ½ lb. ration of bran to 2 lb. on 7th January indicates quite clearly that a supplement of 18 grm. of phosphoric oxide is sufficient to meet the deficiencies of the grass of January and February, although 9 grm. is not.

The rise in osteophagia on cessation of bran feeding is quite clearly shown in all four curves of Chart IX. In Table 43, the fall produced by 2 lb. of bran is immediately converted into a rise on stopping the ration on 23rd February. Within a fortnight 70 per cent. of the cattle again showed marked craving for rotten bones.

The data do not allow of very accurate comparison between the relative efficiency of bran and bonemeal, but it would appear that 2 lb. of bran containing 18 grm. of phosphoric oxide is superior to 3 oz. of bonemeal containing 20 grm. of phosphoric oxide; and hence that the phosphoric oxide of bran is more readily utilizable in digestion than that of bonemeal. Further data upon this point will be offered later, but meantime it is not desired to push the comparison too far, since in the experiments hitherto carried out it has not been always possible to procure cattle with a similar past history in regard to osteophagia.

Of special interest is the experiment showing the effect of feeding maize bran of low phosphorus content in place of wheaten bran of high phosphorus content. Table 45, and the dotted curve of Chart IX, show that even the high quantity of 5 lb. of the maize bran was inadquate to reduce osteophagia. Maize bran has generally a lower phosphorus content than wheat bran and South African grown maize is generally characterized by low phosphorus. This particular sample of maize bran, was, however, picked out on account of the unusually low proportion of phosphoric oxide it contained, different bags of the consignment varying from 0.23 to 0.47 per cent. The average of 0.35 per cent. thus only corresponds to about 0.017 lb. or about 8 grm. of phosphoric oxide in the 5 lb. ration given. As the data show, it has little or no effect in reducing osteophagia, behaving in this respect something like ½ lb. of wheaten bran. In feeding bran as supplementary ration to reduce osteophagia, the character of the bran in regard to phosphorus content must therefore be carefully attended to.

It must also be remembered that whenever a supplementary ration is fed, which, as in the case of bran, is itself a food, there is a corresponding reduction in the amount of natural grass eaten by the cattle. With this comes a reduction of the natural intake of phosphoric oxide, so that in comparing foodstuffs fed in widely varying quantities the quota of phosphorus supplied by the supplement has to be considered along with the varying quota derived from the veld. This point is of little consequence where a small supplement rich in phosphoric oxide is given, but comes out more clearly when large quantities of foods of high calorific value, but of only moderate phosphorus content, are supplied. In the section coming next under discussion it will be observed that maize, even in large amount, is of very little value in reducing osteophagia.

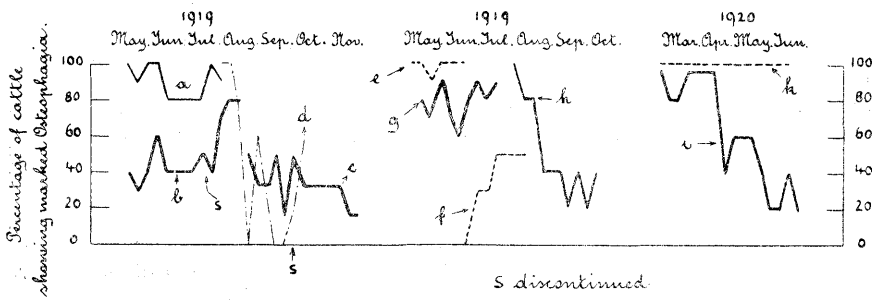
Other Foodstuffs.

In regard to the effect of other foods in reducing osteophagia, it may be mentioned that quite a variety were tried, but that since some of the experiments were unconsciously commenced at a period of the year when osteophagia was about to experience its natural fall, they are of little value. Only those which supply definite evidence need therefore be charted. In any case, now that phosphorus has been nailed down as the primary factor involved in osteophagia, it is possible to deduce the influence of most foods from their analysis. A few of the actual records may be offered, however, as illustrating how well the earlier experiments fit the ultimate conclusions.

Chart X plotted from tables 46 to 54 gives data concerning spineless cactus, maize, beans,, and lucerne hay.

Spineless Cactus.—This was fed early in the investigations in order to ascertain whether the supplementing of the old dry grass

Chart X (Appendix Tables 46 to 54).



a, *b*. Maize, 3 lb. daily.
c. Maize, 5 lb. daily.
d. Maize and lucerne hay.
e, *f*. Spineless cactus.
g. Lucerne hay, 10 lb.
h. Beanmeal, 2 lbs.
i. Lucerne hay and Pretoria veld-hay (kraaled).
k. Lucerne hay.

with a succulent food would itself reduce osteophagia. The cattle were allowed spineless cactus *ad libitum*, but did not eat so much as was expected, contenting themselves with between 20 and 30 lb. per head per day. The data are given in Appendix Table 46, and drawn as dotted curves in the centre of Chart X. In July and August, 1919, a mixed lot of cattle showed an increase of osteophagia in grazing over the veld in spite of the ration of spineless cactus. No influence upon osteophagia was therefore exerted. This is easily understood now, when it is considered that spineless cactus contains over 92 per cent. of water, and that the "dry matter" of the quantity eaten by the cattle only corresponds to about 2 lb. per head per day. In phosphorus content this does probably not exceed the 9 oz. of wheaten bran fed in the experiment already discussed, and already shown to be inadequate. Mere "succulence" of vegetation is therefore of little account.

Beanmeal.—When fed at the rate of 2 lb. per head per day (Table 49), beanmeal may be regarded as accelerating the natural fall of osteophagia for the period under consideration, but it would probably prove ineffective in reducing craving at a time when this

was naturally rising. It was not considered worth while repeating the experiment when the available cattle were so urgently wanted for other experiments. The phosphoric oxide content of the consignment of beanmeal used was 0.72 per cent., and the sample may therefore be equivalated to about one-third of its weight of wheaten bran. Beanmeal may therefore be regarded as incidentally useful if general supplementary feeding for other purposes is being undertaken, but of little value if the chief objective is reduction of osteophagia.

It may be added that, in general, supplementary feeding of cattle on these areas is not practised. The areas are used to rear cattle and the animals are expected to shift as best they can for themselves, and make the grazing cover their requirements even when it is of low quality.

Maize.—From Table 47 and the relevant curves on the chart, it is apparent that 3 lb. of maize per head per day is not effective in reducing osteophagia, although it may to some extent retard its development. In the case of Lot 1, Table 47, the percentage of cattle showing osteophagia did not fall below 80 per cent., and actually rose to 100 per cent., even when the ration was raised to 5 lb. With Lot 2, 40 per cent. of the cattle showed osteophagia when the experiment was commenced on 15th May, and the fluctuation over the ensuing nine weeks of maize feeding is recorded as between 30 per cent. and 60 per cent. Since, however, the craving rose to 80 per cent. three weeks after discontinuing the maize ration, the supplement may be regarded as delaying the development of osteophagia. Table 48 must be ignored since the recorded fall in osteophagia synchronizes with the natural fall due to change in character of the pasture. In the upper half of Table 53 little, if any, effect is indicated as resulting from a daily ration of 5 lb. of maize per head per day. After six weeks of feeding, four out of the five cattle in the test still showed marked craving.

The consignments of maize used in these experiments varied in phosphoric oxide content from 0.42 to 0.52 per cent. (Table 10). Three to five lb. therefore supplies from 0.013 to 0.026 lb., or only from 6 to 12 grm. of phosphoric oxide. Owing to its high calorific value, however, maize does not supplement the natural grazing even to this extent. Its high feeding value tends to reduce the extent of natural grazing in such a way that the natural phosphorus so lost to the animal is not much more than compensated for by the maize itself. This interesting point may be made clearer by considering the phosphorus content of maize in relation to its calorific value or "starch equivalent." Thus 10 lb. of maize would be theoretically sufficient to supply the 8 lb. starch equivalent assumed as necessary for grazing animals per 1,000 lb. live-weight. But if this, as with some of the samples under consideration, only contains 0.42 per cent. phosphoric oxide, only 19 grm. is supplied to the animal. This in itself is regarded as *less than the animal requires*, and hence such maize is in itself deficient in phosphorus. Although therefore at first sight it may seem surprising that liberal maize feeding has no effect upon osteophagia, a little consideration shows that the results recorded are in accordance with theory, and that no marked reduction in osteophagia could be expected, however much maize were fed. This applies to the general run of South African maize, which is known to be low in phosphoric oxide, containing generally not more than two-thirds of the amount present in European samples.

The early maize-feeding experiments thus offer a neat corroboration of the view that osteophagia is directly due to phosphorus deficiency, although of course the later dosing experiments with pure phosphoric acid are more decisive.

Lucerne-hay.—Tables 50, 51, and 52 show that lucerne-hay has little or no effect in reducing osteophagia. In Table 52 osteophagia is shown as increasing in spite of a supplementary ration of 6 lb. of lucerne-hay, while Table 51 and the upper part of Table 50 show continued craving in spite of an allowance of 10 lb. per head per day. The corresponding curves of Chart X illustrate the behaviour at a glance.

In regard to the amount of phosphorus in the lucerne-hay, it may be stated that this roughage, as is so often the case with South African-grown products, was rather poor in phosphoric oxide, although much richer than the veld vegetation itself. The material used in the 1919 experiments contained 0.54 per cent. of phosphoric oxide, while the 1920 supply contained only 0.37 per cent. In the experiment recorded in Table 50 the 10 lb. of lucerne-hay therefore contained 0.037 lb., or about 19 grm. of phosphoric oxide. It might be considered that this should have been sufficient to supplement the natural grazing, but when the low phosphorus-content of the latter for the winter months of experiment (April, May, and June) is taken into consideration, together with the fact that the lucerne-hay ration displaces more than its own weight of natural veld grazing, the results are not surprising. If in addition to the 10 lb. ration of lucerne-hay the cattle be assumed to eat about 15 lb. of "dry matter" in the natural grass, the total intake of phosphoric oxide only works out at about 23 grm. It has already been estimated that more than this quantity is required for prevention of osteophagia, and hence the fact that no diminution in extent of osteophagia occurred on the lucerne ration finds a natural explanation.

With regard to the behaviour of the kraaled cattle represented in the lower half of Table 50, amongst which osteophagia was slowly reduced upon a ration of 10 lb. of lucerne with Pretoria hay *ad libitum*, little need be said. The Pretoria hay contained 0.17 per cent. of phosphoric oxide and the lucerne-hay 0.37 per cent., the mixture supplying approximately 30 grm. of phosphoric oxide per 1,000 lb. live-weight, or above requirements for prevention of osteophagia. The interest of this experiment lies in the fact that when Pretoria hay of 0.17 per cent. phosphoric oxide was made to take the place of the natural grass of 0.08 per cent. phosphoric oxide (by kraaling the animals and so excluding veld grazing), osteophagia was not maintained, but after three months disappeared in three out of four cattle in the experiment. Trials in which Pretoria hay has been fed as sole ration indicate that a poor hay of 0.16 per cent. phosphoric oxide tends to keep animals in a state of equilibrium in regard to osteophagia. If osteophagia is already pronounced it may disappear with some animals after prolonged feeding, while with other animals it may be maintained for at least five or six months. On the other hand, osteophagia did not develop with such a hay in animals which showed no craving at the beginning of the experiment. Hay of this phosphorus-content is therefore regarded as on the border-line of phosphorus sufficiency. If it is of low general feeding value 0.16 per

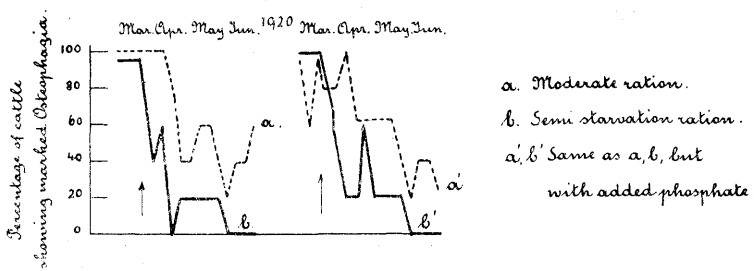
cent. of phospohric oxide is sufficient, since the cattle then have to consume enough to ensure an adequate total phosphorus intake. If, on the other hand, it is of moderately high-feeding value the intake would not provide sufficient phosphorus, and osteophagia would be expected. Thus, if a hay containing 0.16 per cent. of phosphoric oxide had a starch equivalent of 20, the amount required to supply "8 lb. starch equivalent" (for animals of 1,000 lb. live-weight, getting the exercise involved in grazing) would be 40 lb. This would supply 29 grm. of phosphoric oxide, or rather more than sufficient for bare maintenance and for exclusion of osteophagia. If, on the other hand, the hay were of better quality, with a starch equivalent of 30, the amount ingested would only be 24 lb. The phosphoric oxide would then only be 19 grm., and we would expect a slow development of osteophagia, especially in animals with a past history of bone-eating and which therefore "know the trick."

Mixed Ration of Maize and Lucerne-hay.—This may or may not reduce osteophagia, according to circumstances. Table 54 of the Appendix shows that it can, although Lot 2 of Table 53 shows that it does not always do so, and illustrates the fallacy of imagining that any supplementary ration will reduce craving. Although the fact was not fully recognized at the time the experiments were initiated, it is now clear that the behaviour depends upon the gross consumption of phosphorus in the diet, and upon the "availability" of that phosphorus. In practice, however, a supplement of this character is not practicable, since the amount required is so high that the cattle begin to approach stall-feeding conditions. The farmer of the areas concerned of course looks to the veld to supply the "food" of the cattle, and although he may be prepared to allow his stock a small ration of bonemeal, he is not prepared to supplement their general nutrition in any extensive fashion.

Sodium Oxalate and Calcium Hydroxide Experiment.—This experiment, recorded in Tables 55 and 56, is mainly of theoretical interest, but may be mentioned at this point as linking with the question of availability of phosphorus during digestion of food. At the time of the earlier feeding experiments with lucerne-hay the factor of relative displacement of natural veld grazing on different supplementary rations was not taken fully into account, and it was therefore a little disconcerting to find that a high ration of lucerne-hay with a moderate phosphorus-content was not effective in reducing osteophagia, whereas a low ration of bran with a high phosphorus-content was effective. Ten lb. of lucerne-hay containing 0.37 per cent. of phosphoric oxide supply the same amount of phosphorus as 2 lb. of bran containing 1.8 per cent., but the effect in reducing osteophagia was found to be vastly different. This is now explained by the fact that the large ration of lucerne-hay reduces the extent of veld grazing much more than the small ration of bran, and hence partially reduces the natural intake of phosphorus at the same time as it supplements it. But at the time of the earlier experiments it was considered possible that the ratio of lime to phosphoric oxide in the two products might effect the relative ease with which the contained phosphorus was absorbed during digestion, and two experiments were therefore instituted in a tentative attempt to throw some light upon the question. In one, lime was mixed with bran, in amount sufficient to combine with its phosphorus during digestion, in order to ascertain whether such a procedure would lower the efficacy of the bran in

reducing osteophagia. In the other, grazing cattle were dosed with sodium oxalate in considerable daily amount with the idea of rendering the phosphoric oxide of the vegetation more available during digestion by fixing the calcium of the food as the highly insoluble oxalate. A quick ending of this experiment by the poisoning of cattle would of course have answered one part of the question out of hand. It is therefore interesting to record that in a preliminary test cattle were found to tolerate astonishingly high doses of sodium oxalate. In the experiment itself it may be noted from the upper half of Table 55 that the cattle tolerated 30 grm. of sodium oxalate every day for a month, followed by 50 grm. every day for a fortnight. In consideration of the generally accepted view that the soluble oxalates are highly poisonous, it is provisionally legitimate to conclude that the oxalate was not absorbed as such, but partly decomposed by bacterial action and partly combined with calcium of the food and excreted in the faeces as insoluble calcium oxalate. In regard to the original intention of the experiment, it was soon realized that the phosphoric oxide in the grass was so low that even a considerable increase in its "availability" could not be expected to reduce osteophagia, and the test was therefore abandoned.

CHART XI (APPENDIX TABLES 57 AND 58).



In regard to the former experiment, Table 56 shows that no influence was exerted by the calcium hydroxide during digestion of the phosphorus compounds of the bran. Osteophagia disappeared in five out of the six animals in the experiment within a fortnight.

EFFECT OF SEMI-STARVATION UPON OSTEOPHAGIA.

The observation that animals in poor condition are less susceptible to lamsiekte than those in good condition is an old one, and before the significance of osteophagia as precursor to ingestion of toxin was cleared up, it was an observation very difficult to explain. In the course of the work at Armoedsvlakte, however, it was frequently noted that as cattle fell off in condition osteophagia became less acute. The data suitable for tabulation in this direction are few, but an experiment bearing directly upon the point is offered in Appendix Tables 57 and 58. Although the number of cattle used was not large, and the results not so clear cut as they might be, the protocols are of sufficient interest to offer in the form of a chart (XI).

The experiment was carried out in kraals with twenty half-grown "marked cravers" taken from the veld. The lot was divided into two batches, one put on to a moderate ration of 12 lb. of Pretoria hay and 3 lb. maize, the other upon a semi-starvation ration of 6 lb. hay and 1½ lb. maize. Each batch was again divided, five of the animals upon the full ration being supplied with calcium phosphate

in amount (Table 58) sufficient to bring the total phosphoric oxide up to 25 grm., or just over the estimated minimum requirements of the particular cattle concerned.

It was thus hoped to ascertain the influence of semi-starvation upon osteophagia under conditions of both slow and rapid reduction of craving. Unfortunately the number of animals in each test (five) was too small to bring out neat results, and the ration not well adapted to emphasise extremes. If Armoedsvlakte hay instead of Pretoria hay had been available at the moment, and the semi-starvation ration more drastically reduced, still clearer results might have been achieved. The weight of the animals was only 500 to 700 lb. and they did not fall off in condition so fast as was anticipated. Nevertheless the general trend of the data is quite clear, and serves to illustrate the unrecorded observations upon the other cattle. On the simple semi-starvation ration, osteophagia disappeared completely in three weeks, returned in one animal out of the five for a few weeks, and then disappeared altogether, thus showing complete reduction of craving in eight weeks on the low diet. The corresponding batch on twice the amount of the same ration, and incidently therefore on twice the absolute daily intake of phosphorus, fluctuate between 80 per cent. and 20 per cent. osteophagia; but even on 14th June, a month after craving had completely disappeared in the underfed batch, three out of the five still showed marked craving. With the two batches which received an equal daily intake of phosphorus, by addition of different amounts of calcium phosphate, the trend is the same. The half-starved batch lose their craving about a month sooner than the better fed lot, although owing to the added phosphate, four out of the latter five had lost their craving by 14th June (Table 58), as against only two in the similarly fed batch receiving no added phosphate (Table 57).

It may be added that a falling off in condition due to causes other than diet has a similar effect, and that temporary indisposition, diarrhoea, or even the upsetting influence of a railway journey, may effect temporary disappearance of osteophagia. Cattle soon recover their craving, however, as soon as the temporary disturbance wears off.

Artificial Production of Osteophagia.

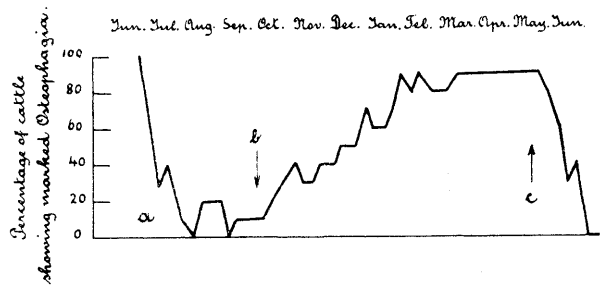
An experiment bearing directly upon the main theme of phosphorus deficiency as cause of osteophagia, but carried out away from the lamsiekte area itself, is of special interest in showing that osteophagia can be induced by feeding upon a ration low in phosphorus independently of veld grazing. Cattle were tested for osteophagia at Armoedsvlakte and then dispatched to Pretoria. After preliminary removal of craving by feeding upon a mixed ration, these cattle were fed in bare kraals, upon a ration of chaff and Fanko in equal proportions by weight. The chaff was itself of relatively low phosphoric oxide content, but in order to reduce the absolute intake as low as possible and at the same time raise the general feeding value of the ration, "Fanko," a breakfast food consisting of the rolled endosperm of maize, was used. The original chaff selected contained 0.11 per cent. phosphoric oxide, and the Fanko 0.9 to 0.12 per cent. Unfortunately it was found later that some of the bales of chaff contained a higher proportion of phosphorus than others, rising in the extreme case to 0.27 per cent., and the ration therefore fluctuated

rather more than intended. Nevertheless the average daily intake of phosphorus was kept sufficiently low to produce osteophagia with ease. The cattle were started off at 5 lb. of chaff and 5 lb. of Fanko per head per day and given more or less from day to day, according to the completeness with which the ration was consumed. Calculated per 1,000 lb. live-weight, the daily intake of phosphorus varied between 6 grm. and 10 grm. of phosphoric oxide per day. The maximum daily ingestion of phosphorus was therefore approximately what it would be upon the lamsiekte areas during the worst months of the year.

The protocols are given in Appendix Table 59 and may be offered as Chart XII.

From the chart or corresponding Table 59, it will be noted that at the commencement of the experiment on 26th June all ten cattle showed osteophagia, but that this rapidly disappeared upon the mixed ration (2 lb. bran, 2 lb. maize, with hay *ad libitum*). One animal (4107) showed a very persistent craving and still displayed osteophagia

CHART XII (APPENDIX TABLE 59).



a. Mixed ration.
b. Chaff and fanko.
c. Chaff and fanko and phosphoric acid.

at the end of September, long after craving had disappeared in at least eight out of the ten cattle. The ration was then changed to the phosphorus-low synthetic ration. The osteophagia immediately commenced to return, appearing in four animals within a month and in seven within three months. By the end of June nine showed craving, but it is interesting to note that the tenth did not develop the bone-eating habit even after continuing the phosphorus-low ration until the middle of May. Apparently an occasional animal does not react to phosphorus deficiency by developing the desire for bones, behaving in this respect, as already suggested, like sheep or horses which do not develop osteophagia upon the natural lamsiekte veld although exposed to the same conditions as grazing cattle.

From 25th May all ten cattle were dosed with 30 c.c. of phosphoric acid, equivalent to 22 grm. of phosphoric oxide, diluted and given in the form of maizemeal paste. The rapid fall in osteophagia, reaching zero in five weeks, shows quite clearly that the previous development of craving was due to phosphorus deficiency and not to any other type of deficiency of which the synthetic ration might be accused. This point is worthy of special mention, since according to accepted standards, the chaff-Fanko diet was low in all three of the known accessory food factors or " vitamines." It is also worthy of mention that although both the calcium and the

phosphorus intake was exceedingly low during the *seven* months of the experiment, no bone lesions (of rachitic or any other type) were noticeable. These points are of special interest in regard to mineral metabolism and vitamine requirements of cattle. They will be dealt with in more detail in later studies.

Suffice it, for the present, to emphasise that osteophagia as such appears to be a simple reflection of phosphorus deficiency.

Veld Vegetation and Soil at Armoedsvlakte.

The character of the vegetation of the lamsiekte areas has already been dealt with in special reference to its extraordinary low content in phosphoric oxide. A systematic study of soil in relation to vegetation and to osteophagia is now in progress, but it is of present interest to recall the earlier data of Juritz, as published in his study of the soils of the Cape Colony, and to refer in particular to the analysis of four samples of Armoedsvlakte soil carried out for us by Dr. Marchand, of the Division of Chemistry, and quoted in Table 61. Reference to the analysis shows that they are all characterised by low phosphorus content, the total phosphoric oxide ranging from 0.03 per cent. to 0.12 per cent. and the " available phosphoric oxide " from 0.0005 per cent. to 0.0022 per cent. (Dyer's method). The lower figures are more characteristic than the higher figures for the general soil of the farm, and it is of special interest to note again how low the phosphorus in the vegetation (Table 8) can fall on this phosphorus-poor soil of an area arid except for the summer rains (Table 7).

The soil is shallow, varying from actual outcrop of dolomitic limestone to an occasional depth of several feet. From a mechanical point of view it behaves like a free-working loam, but owing to its shallow and irregular depth, and the long period of drought, little of it ever comes under the plough.

On dressing with phosphatic manures, a practice rarely if ever carried out in the district, owing to the low value of the land and the uncertain incidence of the rainfall, the dominant lack of phosphorus is reflected both in the density of the vegetation and in its phosphoric oxide content. A manuring experiment in relation to osteophagia, directed by theoretical rather than practical considerations, was carried out in 1919-20, and the results are of considerable interest. One camp was dressed with high-grade superphosphate containing 17 per cent. of water-soluble phosphoric oxide; and another with garden fertilizer containing 14 per cent. of water-soluble phosphoric oxide, 4 per cent. of nitrogen, and 3 per cent. of potash; both at the rate of 500 lb. per acre just after the first October rains in 1919. In May, 1920, these camps were tested against a control unmanured camp, by introducing a batch of ten " reduced cravers " and ten marked cravers into each. From the " permanent controls " (Chart II or Table 5) it will be noted that osteophagia was acute over the general veld area at this time, while in the unmanured camp the extent of osteophagia in the " reduced cravers " admitted on 17th May (Table 62) rose with extraordinary rapidity—from zero to 80 per cent. in a fortnight. In the manured camps, on the other hand, the extent of osteophagia remained low with the " reduced cravers," and practically disappeared in the " marked cravers " in from one to two months (Tables 63 and 64).

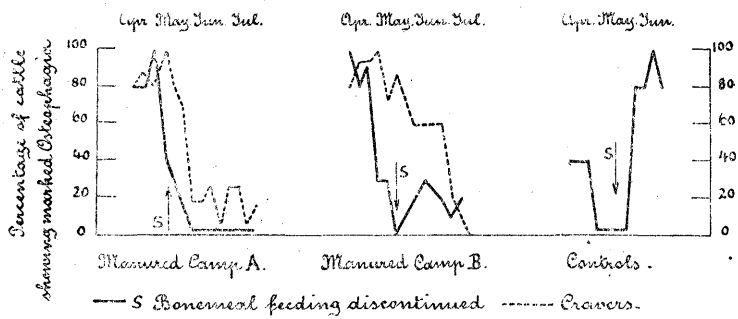
Chart XIII, plotted from Appendix Tables 62, 63, and 64, illustrates the disappearance of osteophagia in the " marked cravers "

on being transferred from the natural veld to the manured camps, in contrast to the development of osteophagia amongst "reduced cravers" in the unmatured camp.

These curves leave no doubt whatever about the fact that heavy phosphatic manuring can so alter the veld as to eliminate osteophagia, and it is interesting to note the actual alteration in phosphorus content of the grass in the camps concerned. From Table 10, in which the analysis of the grass of these camps is recorded, it may be noted that the mature grass of manured camp A (superphosphate) shows 0.30 per cent. of phosphoric oxide; of "manured camp B" (mixed fertilizer), 0.23 per cent.; but of the unmanured control camp, only 0.07 per cent. Manuring with superphosphate increased the phosphoric oxide of the vegetation more than four-fold, thus illustrating the very low level of phosphorus metabolism at which the natural veld vegetation has to mature.

For the benefit of those unfamiliar with the character of the growth on such a veld it may be mentioned that the grasses do not

CHART XIII (TABLES 62, 63, AND 64).



grow evenly or thickly, but in tufts or clumps surrounded by bare patches, representing a sort of radius from which the tuft draws its plant food and its moisture.

From Table 10, it may also be observed that although the phosphorus content of the grass is markedly changed by phosphatic manuring, the low general nutritive value remains much the same. The cattle have to eat large quantities of the mature grass, manured or unmanured, in order to obtain an adequate calorific intake. If from the analyses we estimate the average maintenance intake of the cattle as being about 33 lb. per day per 1,000 lb. body-weight in each case, we get an absolute daily ingestion of about 45 grm. of phosphoric oxide from Camp A, 34 grm. for Camp B, but only 10 grm. for the unmanured Control Camp. Minimum requirements for the prevention of osteophagia have already been estimated as about 27 grm. per 1,000 lb. live-weight, apart from special requirements for rapid growth or large milk yield, and the curves of Chart XIII therefore find a ready explanation in the analysis of the grass. In Camp A, the phosphoric oxide is well above minimum requirements and the osteophagia curve falls very rapidly. In Camp B the phosphoric oxide is not so far above the minimum and the initial fall is slower, although the end result is the same. In the unmanured Control Camp the phosphoric oxide in the grass is less than half the minimum requirements, and the extent of osteophagia shoots up as rapidly in this camp as it shoots down in Camp A.

In controlling osteophagia it does not matter how the cattle get their phosphorus, provided they get it; whether it be by the mouth direct in the form of bonemeal or bran, or indirectly through manure applied to the pasture. Direct administration through the mouth is cheaper, since heavy phosphatic manuring involves a high initial cost exceeding the value of the land itself. But it should not be forgotten that the phosphorus administered to the cattle is returned to the veld and that in the course of time systematic phosphatic feeding will set up a new level of phosphorus equilibrium in the soil, which may be reflected in a natural reduction of osteophagia and an increased capacity of the area to carry vegetation and cattle. The proper way of manuring the lamsiekte soils is suggested as lying through the mouths of the cattle. Apart from the slow incidental enrichment of the soil as a result of feeding bonemeal, or other appropriate phosphatic compound, to guard against lamsiekte, there is the important immediate effect upon the condition of the animals themselves. A marked improvement in condition, sleekness of skin, an air of outward well-being, is noticeable in the bone-fed cattle, and it is considered more than likely that the whole cost of the bonemeal feeding is offset by the enhanced market value of the stock.

As already mentioned, an investigation into the question of phosphorus supply in relation to the growth of young stock and to the milk elimination of cows is now being mapped out, which it is hoped will yield results of very considerable economic value.

In concluding the section of this paper dealing with osteophagia, a summary of the more important points brought out by the experiments may be offered.

Summary of Major Results of Experiments on Osteophagia.

1. The immediate cause of bovine osteophagia is shown to be a deficiency of phosphorus in the veld vegetation of soils very low in phosphorus-content. Osteophagia, or the practice indulged in by the cattle on the lamsiekte areas of eating old bones or other carrion lying about the veld, is in itself a minor complaint to which the farmer pays little attention. Its main importance lies in the fact that it is the precursor to the dreaded "lamsiekte," a disease due to the ingestion of toxic veld carrion infected with a toxicogenic saprophyte. Although osteophagia has never been observed to pass over independently into a disease with an incidence mortality of its own, it is probably of importance in relation to the rate of growth of young stock and to the milk yield of cows.

2. Osteophagia can be produced experimentally by feeding cattle upon an artificial ration very low in phosphorus, and again removed by the simple addition of pure phosphoric acid to the diet.

3. Osteophagia may occur in over 80 per cent. of all cattle grazing over a lamsiekte area all through the year, except for the two or three months of spring and early summer while the vegetation is very young and relatively rich in phosphorus.

4. In 1919-20 the phosphoric oxide in the grass of the experimental farm Armoedsvlakte varied from 0.6 per cent. in the "dry matter" of the young shoots after the first rains down to 0.08 per cent., and even 0.04 per cent. in the old dry grass of the late season (June). Even while the grass is still green and luxuriant it may be

deficient in phosphoric oxide owing to rapid growth under conditions of low phosphorus supply from the soil. The soil itself may contain as little as 0.0005 per cent. of available phosphoric oxide.

Allowing for increased consumption of mature grass by the cattle to compensate for lower general nutritive value, the absolute daily intake of phosphoric oxide from the veld is regarded as ranging between about 37 grm. in November to below 11 grm. in June per 1,000 lb. live-weight for ordinary maintenance consumption of grass. Omitting from consideration the special requirements of rapidly growing young stock and milch cows, the former figure is well above minimum requirements, and osteophagia rapidly disappears during October and November. The latter figure is far below requirements for the prevention of osteophagia, and by May or June all the cattle may show a craving for bones. Usually, however, from 10 to 20 per cent. of a mixed herd do not develop the bone-eating habit at all, behaving in this respect like sheep, which, although exposed to the same veld conditions as cattle, do not react in the same way and do not develop osteophagia.

An intermediate figure of about 27 grm. of phosphoric oxide in the daily consumption of veld vegetation is regarded as somewhere about the point at which osteophagia can develop or disappear in grazing cattle of 1,000 lb. live-weight. This is considered to represent the average minimum requirements for prevention of osteophagia. No precise figures can be offered, since the minimum will vary from animal to animal according to age, sex, and extent of absorption during digestion of the total phosphorus contained in the grass. For old oxen an intake of 27 grm. phosphoric oxide per 1,000 lb. body-weight is probably more than sufficient to prevent osteophagia, while for young cattle and for milch cows it is almost certainly too low. To a certain extent young stock may adjust their phosphorus intake by eating a relatively larger amount of veld grass in proportion to their weight, but in general they develop osteophagia more rapidly on the natural grazing and lose it more slowly in a phosphorus-rich supplement than do older cattle.

5. The relationship between the minimum phosphorus requirements for prevention of osteophagia and the irreducible minimum physiological requirements for life and health has not yet been worked out. But the fact that cattle can show osteophagia for ten months of every year of their lives, and still remain in good health and reproduce their kind, suggests that osteophagia is manifested before the point at which continuous draining of phosphorus from the tissues begins.

6. A daily allowance of 3 oz. of sterilized bonemeal per head is sufficient to maintain osteophagia at a very low level throughout the year. This in itself supplies 20 grm. of phosphoric oxide, which, together with the small amount supplied by the grass, even at the worst season of the year, is sufficient to raise the grass intake above the minimum level of 27 grm. It is, however, not sufficient in all cases, and it is not sufficient to reduce osteophagia rapidly once this has developed. For rapid reduction of craving, 8 oz. to 16 oz. of bonemeal is advised. As soon as osteophagia disappears on the high ration the cattle concerned may be switched over to the low ration, or in the case of milch cows to an intermediate ration.

7. Other phosphorus-rich materials, such as wheaten bran or suitable manufactured phosphates, are equally efficient in reducing

osteophagia, the rate of disappearance of craving being proportional to the amount and the "availability" of the contained phosphorus.

Of the greatest theoretical interest is the fact that even pure phosphoric acid, supplied in the drinking-water or mixed with maize-meal into a paste or dosed by hand, rapidly reduces craving, thus indicating the specific influence of phosphate as such to the exclusion of calcium or other base in combination; at least in so far as the Vryburg farm is concerned.

Based upon equivalence of phosphorus-content, wheaten bran (2 lb.) is regarded as superior to bonemeal (3 oz.), although the latter is regarded as more readily absorbed in digestion than is generally considered to be the case. Bonemeal is superior to mineral phosphate in availability, and is also superior in the sense that it is greedily devoured by the cattle, whereas the mineral phosphate is resented. Mineral phosphate is rendered more available in digestion by conversion into citric-soluble form. The question of the most economical form of phosphorus compound for practical use has not yet been fully worked out, but provisionally the advantage lies with the bonemeal.

Feeding of bonemeal or other phosphorus-rich material in moderate amount is regarded as profitable irrespective of prevention of osteophagia. This is due to the fact that cattle can be so brought into a better marketable condition and superior state of general thrift. It is also regarded as highly probable that phosphorus intake may prove to be a "limiting factor" in the growth of young cattle and in the milk yield of cows.

8. Supplementary foods such as maize and lucerne do not reduce osteophagia unless relatively rich in phosphorus and fed in uneconomical amounts. South African grown maize is characterized by low phosphorus-content, and some samples (below 0.4 per cent. phosphoric oxide) are such that the amount of phosphorus they supply may no more than compensate for the concomitant reduction in natural phosphorus intake, induced by the partial substitution of a supplement of high energy value for the greater weight of veld grazing of lower nutritive value. In any case, however, the cattle are expected to find their livelihood upon the veld, and in practice supplementary rations can only be afforded in small amount. Such supplementary rations should therefore be as rich in phosphorus as possible. In any given diet it is the percentage of phosphorus in relation to the total feeding value which is of account in determining osteophagia. Thus for veld vegetation itself the actual minimum percentage of phosphoric oxide which must be present in order to prevent osteophagia varies with the general nutritive value of the pasture. The better the pasture the higher must be the percentage of phosphorus in its dry matter; and conversely, the poorer the pasture the lower need be its percentage of phosphorus, since the cattle by eating more of the poor quality vegetation thereby raise their absolute daily phosphorus intake. For this reason cattle need not necessarily develop marked osteophagia on a veld containing as little as 0.16 per cent. phosphoric oxide in the dry matter of its vegetation (Pretoria District), although where it falls below 0.10 per cent. (lamsiekte areas) osteophagia would be expected even when the nutritive value of the grass is so low that the grazing consumption approaches the limit of digestive capacity of the cattle.

9. Osteophagia can be reduced by phosphatic manuring of the pasture, but the initial cost of such a proceeding is so high in relation

to the low market value of the land itself that it can hardly be regarded as a practical proposition. Incidental manuring will of course slowly occur through continued phosphatic feeding.

10. Mineral constituents other than phosphorus are apparently present in adequate amount in the veld vegetation. Administration of salts containing calcium, magnesium, sodium, potassium, iron chlorine, and sulphur, do not reduce osteophagia, whereas pure phosphoric acid alone does reduce it very rapidly.

11. Semi-starvation and sickness of any description decrease the degree of osteophagia shown by an animal.

(For tables to this section see pages 1307 to 1361.)

SECTION 7.—SYMPTOMATOLOGY OF LAMSIEKTE.

PLAN OF CONTENTS.