CONCLUSIONS.

1. An organism of the *Clostridium* type can be isolated from material which produces lamsiekte when given to susceptible animals per *os*, or by inoculation subcutaneously, or by other routes. This organism has tentatively been named *Cl. parabotulinum bovis*.

2. This organism produces in culture media an exotoxin which, in unfiltered material or after filtration through a Berkefeld candle, produces typical symptoms of lamsiekte in susceptible animals.

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PLATE 1.

Fig. 1.—Chains of *Cl. parabotulinum bovis* showing portions which did not take the Gram stain.
Fig. 2.—An organism showing terminal spore.
Fig. 3.—Colonies of *Cl. parabotulinum bovis* showing the loose woolly form. Glucose agar shake culture.
Fig. 4.—A rabbit showing symptoms due to the toxin. The position with the head on one side and the staring eye are very characteristic.

SECTION VI.—OSTEOPHAGIA AND PHOSPHORUS DEFICIENCY IN RELATION TO LAMSIEKTE.

(Received December, 1920.)

IT is a generally recognized fact that over large areas of South Africa cattle show an "abnormal craving" or "depraved appetite," particularly for old bones lying about the veld. Indeed, the fact is so well known that farmers in many districts look upon it as a natural thing and only notice it when it becomes so pronounced as to constitute a public nuisance, i.e. when the cattle congregate around the homestead or kaffir huts, devour the washing, bags, clothes, riems, skins, and miscellaneous rubbish; and persistently return when driven away. Such acute manifestations are what is understood by "craving" in the worst districts, and a man brought up in such districts will quite ignore the more subdued "abnormal appetite" manifested only for bones, which is common on so many farms throughout the country.

The term "pica" has been used in the past, by the senior author and others, to denote the depraved appetite of the lamsiekte areas, but it is now desired to modify this terminology and use a word with a more restricted significance. In the ordinary dictionary sense, pica

means depraved appetite of any sort and includes many forms of different origin; such as that shown in certain cases of toxaemia or that observed after the administration of drugs such as apomorphine, as well as indefined cravings exemplified in the "wool-eating" of sheep. Since the abnormal appetite of the cattle in the lamsiekte areas has now been shown to be quite a specific form of pica, removable by the administration of phosphatic compounds, the general term is now too wide. The word osteophagia is more distinctive, since depraved appetite, as precursor of lamsiekte, naturally manifests itself as a craving for old bones (and other carrion) lying about the veld, and only in acute cases passes over into "allotriophagia" or non-discriminating taste for miscellaneous objects. The pica of the lamsiekte areas may therefore be referred to as osteophagia and sharply differentiated from other forms of pica.

Now that the true connexion between osteophagia and lamsiekte is understood, it is easy to realize why some sort of connexion between the two should have been so frequently surmised by the observant farmer. In correspondence, farmers have frequently drawn attention to the fact that when "craving" appeared, lamsiekte was not far off. Indeed, Hutcheon, of the old Cape Veterinary Service, went so far as to explain bone-eating as a definite premonitory symptom, and to formulate a deficiency theory in which lack of lime and phosphate was held to be the actual cause of lamsiekte.

The immediate cause of the disease has now been shown to be a toxin produced by a saprophytic bacterium which infects carcass material of the veld, and it is therefore easy to understand exactly why the Hutcheon hypothesis broke down, and to realize that although it failed to explain lamsiekte it can profitably be revived to explain osteophagia.

Hutcheon's view, however, was empirically useful in breaking a link of a then unknown chain, and it was made the basis of bone-feeding experiments by Borthwick and by Spruell; the former at Witte Clay Rug and the latter at Koopmansfontein, distinctly showing that if bonemeal were supplied regularly at the rate of three to four tablespoonfuls a day, the mortality from lamsiekte was materially reduced. The full connexion is now apparent; bonemeal reduces the osteophagia and so reduces the danger of cattle ingesting toxic carrion. But the Hutcheon hypothesis failed to throw any light upon the immediate cause of the disease, and was abandoned by most veterinarians when it was found that bone-craving and lamsiekte were not invariably associated together; that on some farms where osteophagia was very acute, lamsiekte was altogether unknown. The "bone paradox" was not suspected— that veld bones represented the commonest *cause* of the disease, and that the giving of non-toxic sterilized bonemeal merely reduced the risk of ingestion of toxic veld bones. The causally important link, the toxicogenic saprophyte, was not surmised, so that "cause" and "preventive" were actually confused.

Furthermore, the psychological circumstance already referred to, obscured the truth; the circumstance that farmers, and indeed most veterinarians, took no notice of mild bone-chewing, but regarded it as normal for the greater part of the country. This led to the constant reiteration that lamsiekte occurred independently of pica. Obviously, if this had been true, as the converse is certainly true, and lamsiekte and osteophagia occurred independently of one another, there could be no fundamental relation between the two.

It was not until the real nature of lamsiekte, as a special kind of ptomaine poisoning, had been grasped, and the chain of causation visualized as a whole, that the full distinction between a natural predilection for a sweet bone and a genuine abnormal craving became apparent. Once the idea of the toxicogenic saprophyte was brought in as etiological link, it became obvious that although osteophagia could quite well occur without leading to lamsiekte, and lamsiekte perhaps occur accidentally (as it does experimentally) without osteophagia, lamsiekte could only occur as an enzootic and epizootic disease in areas where bone-eating was fairly pronounced.

The beneficial results obtained by feeding bonemeal were not fully appreciated, since as many farmers reported failure as reported success, in reducing the incidence of lamsiekte. As will be shown later, the explanation of varying success depends upon the quantity of bonemeal given. The amount required to reduce osteophagia *rapidly* is very high, and the ordinary practice of allowing moderate amounts in the form of "licks" is of very little avail.

The recognition of all the factors involved led to the necessity for introducing into the experimental work some system of *measuring* craving on a quantitative basis, so as to bring out the distinction between the comparatively normal and the definitely abnormal, and to allow of expression of both degree and prevalence of osteophagia on some definite chartable basis. This was done by utilizing bones at varying stages of decomposition. It was found quite easy to pick a stinking bone so obnoxious that only those animals showing a very aggravated craving would chew it; and a perfectly bleached bone which practically every animal on the veld would chew, or at least toy with. Intermediate degrees of craving could be identified by intermediate bones, but since this was cumbersome for routine testing of cattle only two grades of bone were habitually used; "sweet or bleached" and "distinctly rotten." The latter were picked out as veld bones which would produce lamsiekte if drenched in sufficient amount, but were then sterilized to render them non-toxic. The former were selected so as to be quite unobjectionable to any beast which showed any clearly defined craving at all, but to be sufficiently objectionable to the true non-craver.

In measuring craving a very simple method of routine testing was adopted. Two sets of troughs, placed at opposite ends of a large enclosure, were provided with test bones, one with the "sweet" and the other with the "sterilized rotten." The cattle to be tested were first admitted to the rotten bones. The number which picked and chewed these was noted and recorded as "marked cravers." Those which refused to touch the rotten bones were then admitted to the sweet bones, and the individuals which picked and chewed again noted. These were recorded as "mild cravers." The remainder which, by the way, would still usually take a ration of sweet *bonemeal* if offered, were entered up as "non-cravers." In the appendix tables offered on pages 1307 to 1361, *marked* osteophagia is indicated by the letter M; *slight* osteophagia, or mild craving, by the letter S; and the absence of osteophagia (non-cravers) by a dash. The letter M, therefore, indicates a degree of craving so dangerous as to lead to ingestion of toxic bones or other carrion, and hence to be a premonitory symptom of lamsiekte wherever the toxicogenic saprophyte and substrate carcass material happen to be present. The letter S is to

be taken rather as an index of appearing or disappearing osteophagia, and is itself not to be regarded as indicating dangerous craving. The dash, indicating absence of osteophagia, means that the animal concerned is, on the date of testing, quite safe from lamsiekte and will not ingest toxic material, however abundantly it may be strewn about the veld.

All the cattle upon the experimental farm Armoedsvlakte, in the Vryburg District of the Cape Province, were tested once a week as a matter of routine, so that the effect of treatment and of seasonal variation of osteophagia could be plotted in the form of curves showing the effect of the particular factor under investigation. Really scientific records of osteophagia were thus obtained for the first time. Most of the records kept at Armoedsvlakte during the years 1919-20 are given in the form of " appendix tables " at the end of this article. Some of these unconsciously overlap owing to the sequence with which results were obtained, the necessity for duplicating experiments under varying veld conditions, and the difficulty of procuring suitable cattle, " cravers " or "non-cravers " as the case might be, just as experiments suggested themselves. Some of the experiments are incomplete, and not always followed up to the most advantageous terminal points, but this was inevitable owing to difficulties in regard to materials and labour, and to the necessity for haste in securing the data of greatest immediate practical consequence.

In the discussion which follows, the plan of charting the most important protocols is adopted, apparently inconclusive experiments being but briefly referred to, and incomplete data being left for later amplification.

In reviewing the appendix tables it is simplest to follow the order of interest rather than the strict chronological order, but a few of the earlier experiments may be discussed first to indicate the sequence of the work. The " grass feeding experiments " may be charted first, since, although the data are limited, they indicate with sufficient clearness the fact that osteophagia is definitely caused by the veld vegetation.

As soon as the significance of osteophagia was clearly recognized, methods for removing it were at once investigated. The natural device of feeding sterilized bonemeal to stop unnatural bone-eating was of course adopted, and the general results of the bonemeal feeding experiments will be discussed presently. Removal of cattle from the veld and stall-feeding on a mixed ration containing bran, was also found to be rapidly effective in reducing osteophagia. In the experiments which required " reduced cravers," i.e. cattle which no longer displayed craving for old bones or other carrion, both methods were employed, and in general a liberal ration of bonemeal and bran was supplied in order to reduce craving as quickly as possible.

In the grass-feeding experiments, designed to show that osteophagia was definitely due to the veld vegetation, " cravers " were first reduced and then fed upon mixed veld hay, and upon individual grasses cut separately from the grazing area. Tables 1 and 2 of the appendix give the protocols concerned, which for convenience may be plotted in the form of Chart I.

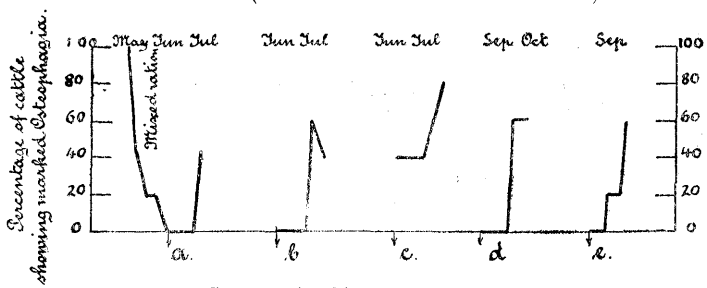
In this, as in subsequent charts, abscissae representing percentage of cattle in the test which show marked craving (M of the tables),

are plotted against time ordinates representing the weekly tests for osteophagia throughout the various months of the year.

The first curve (Table 1) illustrates the rapid reduction of osteophagia upon a mixed ration and its rapid return upon an exclusive ration of veld hay. On a mixed ration of 2 lb. of wheaten bran, 2 lb. of maize, 6 lb. lucerne hay, and 6 lb. of Pretoria hay, osteophagia completely disappeared in four weeks. On then substituting an exclusive ration of grass cut from the veld over which the grazing controls showed osteophagia, the craving for bones returned rapidly; six out of the eight animals again showing marked osteophagia after three weeks feeding.

The four subsequent curves (Table 2) show very clearly that it is not one grass which is implicated, but the veld as a whole. Four of the dominant grasses of the area, "red grass (*Themeda triandra*), "thatch grass" (*Cymbopogon excavatus*), "krul grass" (*Digitaria eriantha*), and "besem gras" (*Aristida uniplumis*), are each shown to produce osteophagia when fed separately to reduced cravers. The cause, then, of the craving for rotten bones and carrion, originates in the veld grass itself.

CHART I. (APPENDIX TABLES 1 AND 2.)



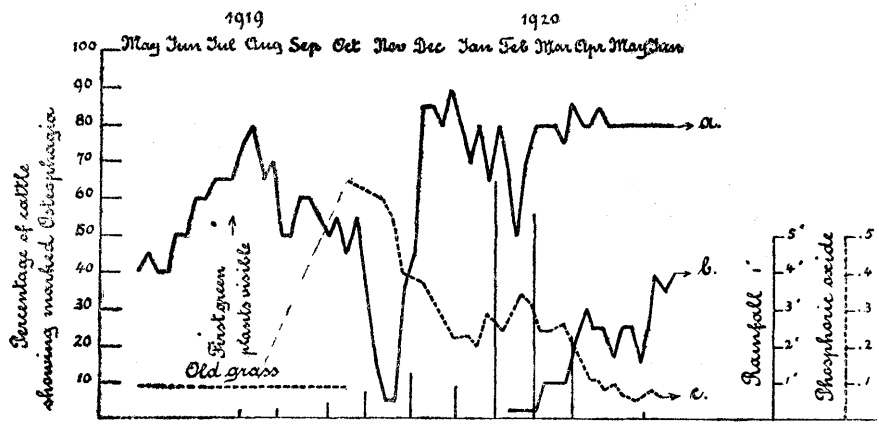
a. Cut mixed veld grasses.
b. Themeda triandra. Red grass.
c. Cymbopogon excavatus. Thatch grass.
d. Digitaria eriantha. Krul grass.
e. Aristida uniplumis. Besem grass.

Appendix Table 3 bears out the data of Tables 1 and 2, but not so neatly, and it is therefore perhaps worthy of mention that on prolonged feeding with hay cut from the Armoedsvlakte veld a disposition is shown for osteophagia to fall off again in intensity. This is probably due to the fact that miscellaneous cut hay is of lower nutritive value than the veld as a whole, in grazing over which cattle have an opportunity to select the best tufts of grass. In consequence, stalled cattle fed exclusively on old dried grass cut at the end of the season are apt to fall off in condition, and associated with this comes a diminution in the degree of osteophagia. This fact will be illustrated by protocols later, but meanwhile it may be mentioned that any circumstance which rapidly reduces the condition of the cattle, or upsets them in any marked way, is frequently accompanied by a temporary loss of osteophagia. A sick beast commonly loses its abnormal craving for bones, but recovers the desire as soon as it returns to normal health.

Analagous to the grass feeding experiments is the "grass ash experiment," of some speculative interest in the early course of the investigations, but of no consequence once the analytical data had

accumulated to such an extent as to cast the " phosphorus deficiency " aspect into solitary relief. The grass ash experiment was initiated on account of a view prevailing amongst certain farmers that lamsiekte was more prevalent over " burned veld " and that grass ash was in itself capable of producing the disease. The data of Appendix Table 4 show quite conclusively that the ash of the veld grass has no injurious effect, and also that it does not in any way induce osteophagia by a faulty relationship between the mineral constituents of the grass. In this " positive sense " the grass ash is without effect, while its " negative significance " is not brought out by the dietetic conditions of the experiment (stable feeding on a mixed ration), although it is abundantly clear from the grass-feeding experiments themselves, especially when the analysis of the veld vegetation is considered (Tables 8, 9, and 10). Later work made it quite clear that phosphorus deficiency of the grass is directly responsible for osteophagia.

CHART II (APPENDIX TABLES 5, 6, 7, AND 8.)



a. Permanent controls, Lot I.
b. Permanent controls, Lot II.
c. Phosphoric oxide in grass.

This brings the discussion conveniently round to a consideration of the natural vegetation and a study of the seasonal variation of osteophagia. The data in this direction may therefore be taken next, leaving the detailed protocols of general feeding experiments to follow.

SEASONAL VARIATION OF OSTEOPHAGIA.

Appendix Tables 5 and 6 give data from which a seasonal variation curve may be plotted, with ordinates showing the percentage of animals which displayed marked osteophagia, and abscissae showing the weekly testing with bones throughout the successive months of the year. From Table 7 may be plotted the variation in phosphorus content of the grass throughout the year expressed as percentage phosphoric oxide of the plant dry matter, and determined by analysis of periodic cuttings. Table 8 gives the rainfall from May, 1919, to May, 1920, which may best be plotted as ordinates representing monthly totals in inches.

Since incidence of osteophagia is intimately related to phosphorus content of the vegetation, and thence to rainfall, all four tables are best offered upon one chart (II).

The seasonal variation curve is drawn from a batch of twenty cattle set aside in May, 1919, to act as " permanent controls." These cattle (Lot 1) grazed continuously over the veld and were not subjected to any experimental treatment. Being a mixed lot, in the sense that some had been on the farm for a considerable time and already showed marked craving, while others had been more recently introduced from areas in which osteophagia was less pronounced, the initial figure of " 40 per cent. osteophagia " is more or less arbitrary.

It will be noted that from May to August there is a steady rise in the proportion which show marked craving (M of the tables); from the initial 40 per cent. to a final 80 per cent. A comparison of May, 1920, shows that the " May craving " should really be recorded as 80 per cent. for the permanent stock of the farm, the 1919 figure being due to dilution with fresh cattle from other areas; and that the nature of the veld is such as to induce a high degree of osteophagia. How long any particular animal would take to develop marked craving depends upon individual idiosyncrasy, upon age and sex, upon the character of the veld upon which it had previously grazed, and upon the season of the year in which it is brought on to a " lamsiekte veld." Generally speaking it takes some months before a batch of " non-cravers " develop " marked craving." In one batch of eighty cattle of mixed origin (not given in a special table but calculated from various tables in the appendix) forwarded through Pretoria, no initial craving was shown on 4th April. Three weeks later 40 per cent. showed osteophagia. In six weeks this had risen to 50 per cent., and in eight weeks to 60 per cent. Thereafter no further increase occurred for two months, the more resistant cattle taking a very long time to acquire the habit of bone-eating.

Sooner or later, however, all except a few cattle develop osteophagia. The few exceptions may never develop it 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. It will be noted from the tables and charts to follow, that Armoedsvlakte cattle, which have once shown osteophagia, but which have been " reduced " by feeding on bonemeal, bran, or other supplementary ration, practically all recover their craving after a few weeks restriction to the phosphorus-deficient veld.

That the lower craving shown on Chart II for May, 1919, as compared with May, 1920, is not due to the character of the particular season, is indicated by the subsidiary curve marked " permanent controls, Lot II." This curve (Table 6) represents a batch of cattle showing no craving at all when first put out to graze in February, 1920. By May, only 30 per cent. of these had developed craving, although the 1919 controls at this time showed a steady level of 80 per cent. osteophagia. The 1920 batch represents a mixed lot comparable with the 1919 batch, and will obviously in time also reach the higher equilibrium.

From May to August, therefore, and again from December to May, with the exception of a momentary reduction in February, the extent of osteophagia displayed by the regular stock of the experimental farm is high, and up to 85 per cent. of the total herd may be observed to eat rotten bones. In the intervening months the craving fluctuates, although only for a very short period is it really

low (November). Reference to the curve of Chart II (Table 5) shows that from August, just as the first green plants begin to make their appearance, and the sap begins to rise in the still living vegetation, the extent of osteophagia begins to diminish. From August to October the amount of young green vegetation which the cattle can secure, even on ardent search, is very small, and the diminution in osteophagia is slow and irregular. Even by 20th October it has only fallen from 80 per cent. to 55 per cent. (Table 5), although immediately after this, following the effect of the slight rainfall of October and the heavier rainfall of November (Table 7) upon the young vegetation, the fall is very rapid. By 27th October, after the slight rainfall of 1 inch distributed over August, September, and early October, the proportion of cattle still liable to eat rotten bones has fallen to 35 per cent. Following the heavier rainfall of 29th October, 1st November, and 6th November, and rapid response of the young spring vegetation, comes an almost complete disappearance of osteophagia. In the testings of 10th and 17th November, only one animal out of the twenty (5 per cent.) shows any disposition to touch "sterilized rotten bones," although on the latter date eight out of the twenty (or 40 per cent.) show a predilection for "sweet bones." These cattle—"slight cravers" marked S in Table 4—are no longer liable to contract lamsiekte by ingesting toxic carrion, but are not far from the border-line of the more aggravated and dangerous craving.

From 7th November to 28th December very little rain fell, while the sunshine was strong and the grass rapidly wilted. Associated with this may be noted a rapid rise in the osteophagia curve to 35 per cent. by 24th November, and up to the previously high level of 85 per cent. by 8th December.

The curve thus shows pronounced osteophagia while the cattle were grazing upon the old grass of the preceding season, reduced craving as the young spring vegetation began to shoot, practically no craving after the beneficial effect of the rains upon the young grass, but a recrudescence of craving when the young grass wilted and shrivelled up.

In the middle of January, 1920, the drought again broke, with nearly 2 inches of rain between 13th and 19th, while on the last three days of the month over 3½ inches were recorded (Table 7). The pasture rapidly recovered and it was naturally anticipated that the craving would again disappear, as it did after the lighter rain of October. The unexpected happened, however, and notwithstanding the abundant supply of green grass and the absence of wilting, the osteophagia did not fall to the previous 5 per cent., but only to 50 per cent. As the age of the grass advanced to maturity, the osteophagia curve again rose and, in spite of the heavy February rainfall, stood at 80 per cent. on 1st March. Thereafter, through April, May, and June, during which quarter the total rainfall was only about one-fifth of an inch, the extent of craving remained high, and it is anticipated that the records for the later months will show a fluctuation around 80 per cent. until the young green grass once more appears.

Summarizing, then, it may be stated that the permanent stock of a bad lamsiekte farm, such as Armoedsvlakte, is likely to show *marked osteophagia* in well over three-quarters of the entire herd, for *ten months of the year,* and that only for a *few weeks* at most is the craving likely to disappear or to remain at a level below one-third of the herd.

The relation between the extent of osteophagia in the cattle and the character of the grass was somewhat puzzling until the analyses of periodic samples were compared, since it was naturally thought that the craving would not rise so long as the grass remained green and luxuriant. The data given in Table 8, and plotted in Chart II, show, however, that the phosphorus content falls off rapidly, while the vegetation is growing quickly. In the coming year a still closer study of the vegetation is contemplated, but the provisional data are of great interest.

During May and June, when the craving is at its height, old grass cut from the grazing area shows the extraordinarily low proportion of 0.04 to 0.08 per cent. of phosphoric oxide, expressed upon the dry matter. The actual figure varies somewhat in different samples of grass. An average sample cut in May, 1919, showed 0.08 per cent., while different samples from three different camps in May and June, 1920, varied from 0.04 to 0.13 per cent.

During the period of early growth in October and early November the young grass showed from 0.65 to 0.55 per cent. of phosphoric oxide (on the dry matter), or about eight times as much as the old June vegetation—fifteen times as much if extreme figures are taken. This corresponds to the fall in the extent of bone-eating shown by the cattle, and, indeed, it may be noted that the osteophagia curve and the phosphoric oxide curve are roughly inverse to one another. By the middle of October young succulent green vegetation, with relatively high phosphorus-content, was moderately abundant, and it may be safely presumed that by this time the cattle procured sufficient of it to exclude the old dried grass of the preceding season from their daily grazing. It is just then that the sudden fall in osteophagia became apparent, the earlier slow fall from the middle of August being explainable on the grounds that, although green vegetation was apparent as early as 1st August, it was so scarce that the cattle still had to depend upon the old grass for their major food intake. The slow and irregular fall in August, September, and early October may be regarded as the effect of averaging out the old grass of the preceding season with its low content of 0.08 per cent. phosphoric oxide, with the young shoots showing over 0.6 per cent.

By 20th November the new vegetation was considerably more abundant and rapidly wilting under the influence of the drought following the earlier rain. The phosphoric oxide had then fallen to 0.4 per cent. By 8th December it had fallen to 0.32 per cent., while the osteophagia had once more returned to a high level. The quarter inch fall of rain on 4th December did little to relieve the wilting, and it was not until after the heavy rains of the middle of January that the grass again showed a fresh luxuriance of growth. During the latter period of the dry weather, from 22nd December to 13th January, the phosphoric oxide had fallen as low as 0.22 per cent., and it was difficult to know whether to attribute the high proportion of osteophagia to the wilting as such, or to the diminishing phosphoric oxide. This point, however, was cleared up by the second rains, which stimulated the grass to rapid luxuriant growth, left the phosphorus-content low, and was *not* succeeded by wilting. The fresh growth was accompanied by a small rise in the phosphoric oxide content of from 0.22 per cent. on 15th January to 0.34 per cent. by 17th

February, associated with a small fall in osteophagia from 85 per cent. down to 50 per cent. of all the cattle in the test. As, however, the grass continued to develop, the phosphoric oxide steadily fell again, had fallen to 0.24 per cent. by the beginning of March, by the time that the osteophagia had returned to 80 per cent. Since the extent of bone-eating remained high in spite of the fresh character of the vegetation and the absence of wilting, it would appear that wilting as such was an incidental concomitant of the earlier rise; that phosphorus supply is the dominant factor; and that it is quite unnecessary to assume any production of toxic substances in the vegetation during wilting, as has been done by some observers. If, on the analogy of frost-wilting of sorghum, wilted grass is in itself in any way injurious, it is not necessary to assume any direct correlation with osteophagia.

In thus discussing the relationship between the phosphoric oxide of the vegetation and the extent of osteophagia amongst the grazing cattle, it must be emphasized that the present data are too meagre for a very detailed study. Nevertheless they allow of some interesting deductions concerning phosphorus requirements in bovine metabolism. The actual satisfying of the demands for phosphorus of the cattle of course depends mainly upon three factors—(*a*) the proportion in the grass, (*b*) the extent to which this is in a form readily assimilated during digestion, and (*c*) the gross intake of grass. As the proportion of phosphoric oxide falls with advancing age, the vegetation becomes coarser and less nutritious, and a larger amount has to be eaten in order to cover the daily requirements of the cattle. The increasing intake of more mature grass would tend to balance the decreasing proportion of phosphorus, but for the fact that the diminution in phosphorus-content proceeds much more rapidly than the falling off in nutritive value, while at the same time the "availability" of the phosphorus is undergoing reduction. Unfortunately there is no easy way of accurately estimating the daily quantity of veld vegetation ingested by cattle grazing over such wide areas, and experiments upon the digestibility of the grass and availability of contained phosphorus at various stages of growth, have not yet been commenced.

A rough approximation may, however, be obtained from the analysis of the vegetation by assuming digestive coefficients on the basis of European work, and assuming that the cattle naturally regulate their grazing intake to their caloric requirements.

A few proximate analyses are offered in Appendix Table 9, from which it is apparent that for isodynamic intake there would be consumed well over twice as much "dry matter" in the form of old June grass as in the form of the young pasture of November. The grass begins to show infloresence about February, and in assuming rough "starch values" in Table 9, calculations have been based upon a rich pasture grass for the early stages of growth, grading down to a poor meadow hay for the obviously poor dry grass of June. The young grass of November is highly nutritious, with over 19 per cent. of crude protein, as expressed upon the dry matter, while by April it is fibrous and shows less than 5 per cent. of crude protein. The character of the grass is reflected at once in the condition of the cattle, which fatten up in a really remarkable fashion with the change from the rainless winter to the warm wet early summer; reflected especially in young stock and in cows.

If, for the moment, the special requirements for growth and milk production are disregarded and only the ordinary requirements of the grazing animals considered, a conservative intake corresponding to a "starch equivalent" of 8 lb. per 1,000 lb. live-weight per day may be made to serve as basis for calculating phosphorus intake. On such a basis the actual intake of the November grass would be about 14 lb. dry matter, or over 60 lb. of the young green grass. The phosphoric oxide contained in this, on the analytical basis of 0.6 per cent. upon the dry matter, would be 0.084 lb., or approximately 38 grm., in a form readily utilized in digestion. Expressed per 1,000 kilos, this corresponds to about 84 grm. By May or June, however, cattle of 1,000 lb. live-weight would have to ingest over 30 lb. of "dry matter" of the old grass in order to procure the same "starch equivalent," although in the process they would only get about 0.4 lb. of true digestible protein, and be surviving on a level of protein metabolism unpleasantly low for growing stock. This 30 lb. of dry matter, with an average phosphoric oxide-content of 0.08 per cent. as shown for May and June, only corresponds to 0.024 lb., or less than 11 grm. of phosphoric oxide, and this in a form probably less "available" in digestion. Expressed per 1,000 kilos body-weight, this corresponds to about 24 grm. total "food phosphoric oxide."

During intermediate periods a grazing of intermediate feeding value is obtained, but, except for the month of November, the phosphorus intake of the cattle is always low owing to the fact that the percentage of phosphoric oxide decreases much faster than the nutritive value. Thus for the grass sampled on 15th January (Table 9) the feeding value is not much inferior to that of November. It still contains 14 per cent. of crude protein and a starch equivalent of over 50, expressed on the dry matter. But its phosphoric oxide-content of 0.22 per cent. only corresponds to an absolute daily intake of about 16 grm. for the 8 lb. starch equivalent presumably required by the grazing cattle for mere livelihood per 1,000 lb. body-weight.

It is apparent, then, that the seasonal limits for the absolute daily intake of phosphoric oxide range from about 38 grm. early in November to below 11 grm. in June. The former figure obviously represents sufficient for ordinary requirements (excluding special requirements such as milk production), while the latter figure is obviously far below that at which marked osteophagia develops, since even in the middle of January, when the intake corresponds to 16 grm., a high incidence of osteophagia is recorded. A fair idea of the "minimum requirements," i.e. the amount above which osteophagia will not develop, may be obtained by calculating from the "minimum" of the osteophagia curve of Chart II. This occurs towards the end of November, the minimum of 5 per cent. osteophagia of 17th November changing to 35 per cent. on 24th November, 45 per cent. on 1st December, and 85 per cent. on 8th December. For the grass sampled on 25th November, 0.4 per cent. phosphoric oxide is recorded on the dry matter. The nutritive value is still high, however (although the grass is wilting), and an estimate of 15 lb. of plant dry matter may be made for the daily grazing per 1,000 lb. body-weight. This gives a phosphoric oxide intake of 27 grm. A similar calculation for the period in February, at which the slight fall in osteophagia again changes to a rise, gives substantially the same figure. A calculation made for 4th March on the more fibrous vegetation gives about 22 grm. at a time when the osteophagia had risen to its original 80 per cent.

The average physiological limit for development of osteophagia is therefore indicated at about 27 grm. phosphoric oxide in the day's grazing; this for cattle of about 1,000 lb. live-weight consuming a "starch equivalent" of about 8 lb. Expressed per 1,000 kilos live-weight, this corresponds to about 60 grm. of phosphoric oxide in the grass. The seasonal range of phosphoric oxide which the cattle normally obtain varies from well above this figure (38 grm.) to well below it (11 grm.). Individuals may vary in the limit at which they respond to phosphorus shortage by the development of osteophagia, but for 80 per cent. of the permanent controls at Armoedsvlakte "bone-eating" may be regarded as setting in as soon as the phosphoric oxide obtained in the course of the day's grazing falls seriously below 27 grm. per 1,000 lb. body-weight, or per 8 lb. "starch equivalent." Expressed another way, one might say that for absence of osteophagia the natural vegetation should contain about 0.75 per cent. phosphoric oxide expressed on its starch equivalent, or 0.45 per cent. to 0.15 per cent. phosphoric oxide in the dry matter of the grass, according as the grass is young and nutritious with a starch equivalent rising to 60 (on the dry matter), or old and fibrous with a starch equivalent falling to 20. As already pointed out, the poorer the vegetation the less phosphoric oxide need it carry, since low quality tends to be balanced out by the eating of large quantity.

An interesting question may now be raised. Does this minimum of phosphorus required for avoidance of osteophagia correspond to the metabolic minimum required for the normal physiological functions of the body? It is hoped to acquire data in the future which will allow of an estimate of the degree of approximation of these two minima, but provisionally one may assume that osteophagia develops before the bare physiological minimum is reached. It is incredible that cattle could have their being and produce their kind, upon a diet which for ten months of each year of their lives is far below their physiological minimum phosphorus requirements, and which for the remaining two months is ony slightly above it. If the natural supply from the veld were below the physiological minimum, one would expect a definite "phosphorus deficiency disease" to develop, ending inevitably in death. One may therefore regard the veld conditions as such that, although the cattle must get at least their physiological minimum requirements, they get so much less than their optimum requirements as to induce a cry for more. The cattle live for ten months of the year at a very low level of phosphorus metabolism, and osteophagia is the "cry for more."

There is very little doubt that here on these lamsiekte areas there exists under natural conditions of practical cattle-rearing a state of affairs which many nutrition experts would regard as incredible. It is therefore of great interest to turn to the literature on phosphorus metabolism in cattle and note the prevailing opinions regarding exogenous physiological minima; by exogenous physiological minimum being understood that amount of phosphorus which must be present in the food in order to prevent loss of phosphorus from the tissues of the body.

A precise figure is very difficult to arrive at, since the phosphorus actually present in the different foods is not absorbed to the same extent in digestion, absorption being generally regarded as varying from about one-third of the total present in some foods to over half

that present in others. For stable-fed cattle on a mixed ration in which hay preponderates, the figures of Kellner may be taken by way of illustrating informed opinion upon phosphorus requirements. Kellner's estimate of the minimum for the resting ox is 50 grm. phosphoric oxide per 1,000 kilo body-weight. For cows in milk he adds to this, three times the amount of phosphoric oxide eliminated in the milk, thus arriving at from 60 to 140 grm. according to the milk yield and period of lactation. For calves Kellner estimates a daily retention of about 20 grm for tissue formation, and hence a high daily requirement in the food of from 40 to 60 grm., working out at somewhere near 200 grm. if expressed per 1,000 kilo body-weight. Converting these figures into requirements per 1,000 lb. body-weight, they would run 23 grm. for oxen, 30 to 60 grm. for cows, and still more for young stock during the first year of life.

Even assuming that young stock and cows with calf at foot, ingest the maximum quantity of veld grass which they are capable of digesting, it is difficult to see how they could approach Kellner's minimum during at least nine months of the year. Even oxen would find it difficult in the months from April to July when the phosphoric oxide in the dry matter is falling from 0.12 per cent. down to 0.08 per cent. or less. It has already been estimated that during these months their daily intake may fall below 11 grm. or less than half Kellner's figure, although during the best months of November they can easily acquire 50 per cent. more than his estimate of 23 grm. per 1,000 lb. live-weight. Ignoring then the special requirements of growing stock and milch cows, one is forced to conclude that even for oxen the true physiological minimum of phosphorus, for life and health, is considerably lower than that generally considered to be the case. No estimate has yet been made of the rate of phosphorus storage in young cattle growing up on these lamsiekte areas, nor of the phosphorus eliminated by cows in the form of milk, but it is hoped to acquire such data in the near future. The separate study of the existing protocols on osteophagia in calves, cows, and oxen, is being postponed until more detailed experimental work is completed, but in passing it may be mentioned that young stock, and cows with calves, lose this craving more slowly on a supplementary phosphorus-rich ration than do oxen; and also redevelop osteophagia more rapidly when again restricted to the veld vegetation. The roughly estimated figure of 27 grm. phosphoric oxide per 1,000 lb. live-weight as daily intake in the grazing, for the level at which osteophagia begins to develop, refers to mixed stock of varying age. Later work will show the divergence in needs of young stock and old oxen.

Feeding Experiments.

The various experiments in which supplementary rations were fed to the grazing cattle to ascertain their effect upon osteophagia, were commenced before the data bearing upon the natural phosphorus intake of the cattle were fully worked up. They bear out in striking fashion the general contention that phosphorus shortage is the only really significant factor in the development of osteophagia, and that other factors, if they exist, are quite subsidiary. Of the feeding experiments, those dealing with the administration of bonemeal and phosphatic salts may be taken first, as being of greatest interest.

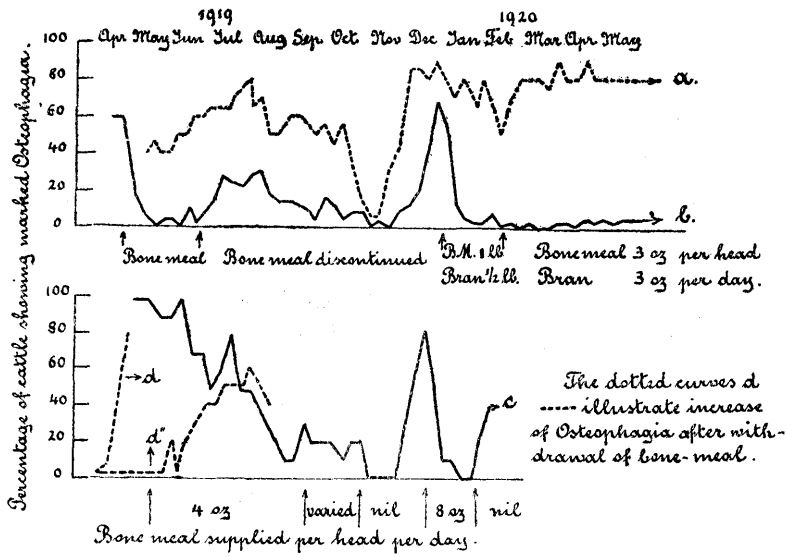
Bonemeal Administration.

Once the true significance of bone-craving in the etiology of lamsiekte had been grasped, the first natural step in the investigations was the study of the influence of feeding sterilized bonemeal.

The first trials showed that sterilized bonemeal was indeed capable of removing osteophagia, but brought out very clearly the fact that to effect rapid disappearance the quantities given must be very high, thus explaining the negative effect upon the incidence of lamsiekte so frequently obtained in earlier experiments, and so frequently reported by farmers who had tried bonemeal administration in the form of "licks," or even by dosing with moderately large quantities at irregular intervals.

In the experiments at Armoedsvlakte the actual quantity administered to the cattle was controlled either by dosing, or by

Chart III (Appendix Tables 11, 12, and 13).



a. Permanent controls for comparison.
b. 50 working oxen.
c. 10 cattle on varying amounts of bonemeal.

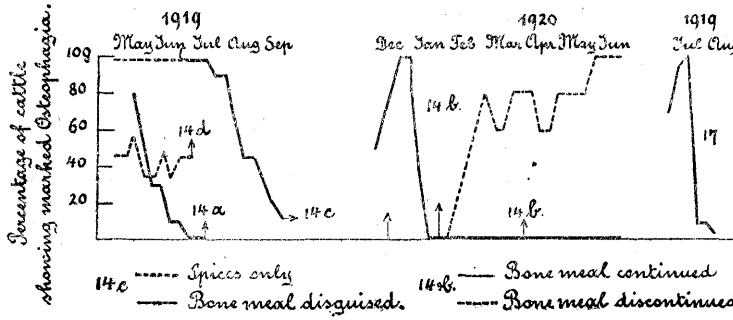
offering the prescribed amount to individual animals in individual troughs, thus obviating the risk of stronger animals securing more than their prescribed share, at the expense of weaker animals.

The following Charts 3 and 4 plotted from Appendix Tables 11 to 17 illustrate the general results with bonemeal, and may be discussed together.

In Chart III the "permanent control" curve of Chart II is repeated for the sake of easy reference. From the lower curve showing ten cattle upon varying allowance of bonemeal (or from the corresponding Table 12), it is apparent that even so liberal a supply as 4 oz. bonemeal per head per day is not sufficient to reduce the prevalence of osteophagia with any degree of rapidity. On 19th June, when the experiment was commenced, 70 per cent. of the cattle (Table 12) were bone-eaters, while on 8th September, nearly three months later, 30 per

cent. still showed marked craving; the fluctuations ranging between 10 per cent. and 80 per cent during the interval. In view of the fact that on 28th July, after six weeks administration of 4 oz. of bonemeal per head per day, 50 per cent. of the cattle still showed osteophagia, as against 75 per cent. in the permanent controls, it is clear that this amount is not high enough to effect a rapid reduction of craving. At the same time it is obviously sufficient to produce a beneficial effect, since the osteophagia curve for these cattle is falling while the control curve is rising; and while the two lots of cattle indicated by the two lower dotted curves (Table 13) are rapidly redeveloping osteophagia after having been previously reduced with bonemeal. There can thus be no question as to the beneficial effect of the daily ration of 4 oz. of bonemeal, but any attempt to cut short an outbreak of lamsiekte by using this quantity would generally prove abortive; 50 per cent. of the mixed herd being still liable to pick up toxic veld carrion after six weeks feeding, and 30 per cent. in danger even on

CHART IV (APPENDIX TABLES 14 AND 17).



14*a*. 8 oz. bonemeal daily.
14*b*. 4 oz. bonemeal daily.
14*c*. 8 oz. bonemeal daily, disguised with spices.
14*d*. 4 oz. bonemeal twice a week.
17. Special ration (see table 17).

8th September after nearly three months of treatment. Only where osteophagia was of recent development, as in the December portion of the curve in Chart IV, would 4 oz. be sufficient to reduce it. In this case, in which 4 oz. of bonemeal is indicated as adequate, osteophagia had disappeared naturally in November, redeveloped in December as the phosphoric oxide in the grass diminished, but was easily removed again owing to the fact that the shortage of veld phosphorus was not yet very acute.

A still lower administration of bonemeal, at the rate of 4 oz. given twice a week, as indicated by the dotted curve on the left in Chart IV. (Table 14*d*) is of no practical value at all.

With 8 oz. of bonemeal per head per day, however, the effect is much more rapid, as shown in Charts 3 and 4, or Tables 12, 14*a*, 14*c*.

In from three weeks to six weeks the osteophagia disappeared, the rate depending upon the previous history of the cattle and upon their age and sex. The tables are not recorded in sufficient detail to permit of close analysis of all factors, but it is again quite apparent that if osteophagia is of recent development it is easily removed, whereas if it is of long-standing character it is more difficult to cure with bonemeal. Thus from the curves on the left of Chart IV (Tables

14*a* and 14*c*) the rate of disappearance in May, June, and July is much slower than indicated in Chart III (Table 12) for December. From what has already been stated in discussing the variations in phosphoric oxide content of the natural vegetation during different periods of the year, this behaviour is easily understood. The grass of December has just fallen below the minimum requirements in phosphoric oxide and relatively little bonemeal is required to meet the deficit.

Very rapid reduction of osteophagia can be affected by feeding still higher quantities of bonemeal, and 1 lb. per head per day is usually sufficient to bring down craving to very small limits in two to four weeks at any time. In the charts and tables it so happens that wherever so high a ration is recorded, a smaller quantity would have sufficed to reduce the osteophagia of the particular period concerned, but it may be stated as a matter of subsequent general experience in reducing craving for experimental purposes, that so high a ration is rapidly effective at any period of the year. There are a few exceptions in which a few refractory animals or " persistent cravers " continue to look for veld bones even after a month of high rationing with 1 lb. of bonemeal per head per day, but in this, perhaps, the element of fixity of habit must be taken into consideration.

When bonemeal and bran are both fed together in liberal amount the maximum rapidity is achieved in reducing osteophagia. The curve on the extreme right of Chart IV (Table 17) illustrates a case in which cravers were reduced for experimental purposes in August, when the extent of craving had been maintained for some time, and offers an extreme instance. Nineteen animals were kraaled and fed upon a mixed ration of maize and hay with addition of 3 lb. of wheaten bran and ½ lb. bonemeal. In one week osteophagia had disappeared in seventeen out of the nineteen animals, while at the end of the following week only one animal still showed marked craving. This appears to represent about the limit of rapidity of reduction of osteophagia.

But although it is economical in the long run to reduce osteophagia as rapidly as possible when an actual outbreak of lamsiekte has occurred, or is feared, and in this way reduce the period of risk of picking up toxic veld carrion while the farm is being thoroughly cleaned, it is by no means necessary to continue this high ration once osteophagia has been reduced to negligible limits. A glance at the last part of the curve for working oxen on Chart III (Table 11) shows that a small ration of 3 oz. of bonemeal (with 3 oz. of bran) is sufficient to maintain the lower level more or less indefinitely. Of the 50 oxen concerned, only two show recrudescence of marked craving on this " maintenance ration of bonemeal." The 3 oz. of bonemeal supplies about 20 grm. of phosphoric oxide, which together with the low natural daily intake from the vegetation, equivalent to about 11 grm. in April and May, is sufficient to meet the requirements of the oxen even if the phosphorus in the bonemeal is not quite so available as that in the vegetation itself.

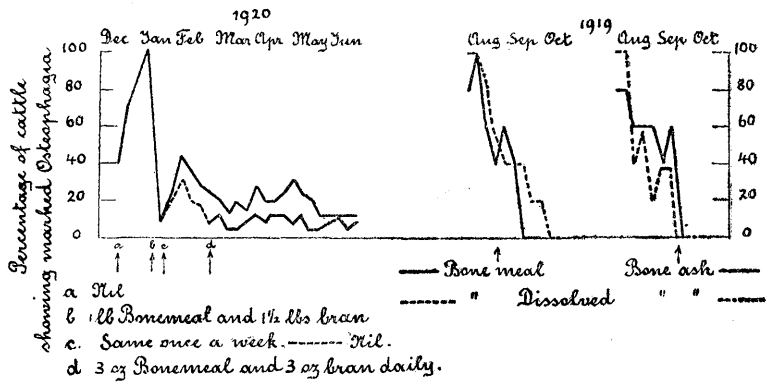
The middle curve of Chart IV shows this in even more striking fashion. From Table 14*b* it may be noted that for the ten " reduced cravers " which had just redeveloped osteophagia on being turned out to veld grazing during the month of December, the 4 oz. ration of bonemeal sufficed to reduce it again in three weeks. Of these ten, five continued to receive the moderate bonemeal ration and showed no

return of osteophagia, while of the five deprived of the ration four redeveloped osteophagia by 1st March and the remaining one by 24th May.

This test, however, involved so few cattle that it could not be regarded as conclusive and a fresh batch of forty-nine animals was put into experiment for the express purpose of testing the point. The data are given in Appendix Table 15 and in the first half of accompanying Chart V.

At the commencement of the experiment on 15th December 40 per cent. of the cattle showed osteophagia (Table 15), rising to 100 per cent. by 6th January. On 8th January 1 lb. of bonemeal and ½ lb. bran were given per head per day. Within ten days the osteophagia had again dropped to 8 per cent. (4 out of 49 cattle), thus again illustrating the rapidity with which the craving can disappear

CHART V (APPENDIX TABLES 15 AND 18).



provided it is of recent origin and the supplementary ration contains sufficient phosphorus. The cattle were then divided into two groups, one receiving the same ration once a week instead of daily, and the other receiving no ration at all. In both groups the craving began to return almost at once (22nd and 26th January) and fluctuated between 16 per cent. and 44 per cent. over the ensuing three weeks. On 17th February all 49 cattle were given an allowance of 3 oz. of bonemeal and 3 oz. of bran in order to ascertain the effect of a small ration in keeping down the level of osteophagia. It will be noted from the chart that the general level of craving is further reduced, and then maintained more or less constant over the next four months. The upper portion of the divided graphs on Chart V represents the batch showing 28 per cent. osteophagia at the time of receiving the small ration, and these fluctuate thereafter between their initial craving and a lower craving of 12 per cent., settling down to a steady 12 per cent. by the middle of May, at a time when 80 per cent. of the permanent controls show osteophagia. The lower half of the graph shows a drop from the initial extent of osteophagia and a fluctuation between 4 per cent. and 12 per cent. (one to three animals out of 25) during the ensuing months. These cattle, it may be mentioned, were a mixed lot containing a number of young animals whose requirements were presumably high per unit of weight. Unfortunately, no weighing machine was available on the farm at the time of the

experiment, and it is not possible to correlate the ration per head with the estimated requirements of phosphoric oxide, but the experiment at least serves to show that for the majority of the animals 4 oz. of bonemeal per head per day, sufficed to meet the deficiency of the veld grazing. This 4 oz. of bonemeal contained 27 grm. of phosphoric oxide, the daily intake which has been estimated as necessary to prevent osteophagia in oxen of 1,000 lb. live-weight. For oxen then, this ration would be theoretically sufficient irrespective of the grazing, provided the phosphoric oxide of bonemeal were as " available " as the phosphoric oxide of the grass. In reality it is probably lower, but 4 oz. of bonemeal is still sufficient to meet the deficiencies of the vegetation. For younger stock the 4 oz. per head represents a higher proportion per unit of body-weight, but owing to the higher requirements for bone formation the allowance is perhaps not too liberal, and just suffices to prevent osteophagia from developing.

Summarizing the data of the various experiments with bonemeal it may therefore be stated that 4 oz. per head per day is sufficient to maintain osteophagia at a low level once it has been reduced by higher rationing (1 lb.) or by the natural vegetation appearing after the first rains of early summer. There are, however, still a few cattle which require a higher daily allowance, and for cows in milk it is advisable to supply it. To exclude osteophagia in cows would probably require a regular rationing of somewhere about 6 to 8 oz., the cost of which might hardly be justified by the reduction of the vanishing risk to no risk at all, although it would probably be justified by enhanced condition and milk yield. When the other important measure in guarding against lamsiekte is observed, i.e. the careful removal of all carcass material from the veld, the risk attaching to a low residual craving is not great. A ration of 4 oz. of bonemeal, however, is profitable irrespective of the degree of protection it offers against lamsiekte, being returned in the improved condition of the stock and their enhanced market value. At the same time it is generally sufficient to minimize the risk attaching to overlooked fragments of carrion and so provide a second measure of protection against the dreaded disease.

The question of the most profitable amount of bonemeal to feed from the point of view of improved condition of the cattle, in distinction to the amount of bonemeal required to protect against lamsiekte, is now under investigation.

In passing it must be emphasised that individual idiosyncrasy plays a considerable rôle in the persistence of osteophagia. An odd animal here and there will display bone-eating on a high ration of bonemeal long after its fellows have ceased. On a moderate ration the craving may disappear and reappear in intermittent fashion with different animals, thus giving a degree of irregularity to the osteophagia curves which could only be smoothed out by charting a " statistically large " number of animals. A detailed study of the appendix tables illustrates the general behaviour. Thus for the cattle on bonemeal and bran in Table 15, animal 244 shows marked craving right through six months of experiment; with animal 4828 the craving disappears in January, shows up as a recrudescence on 5th April and 26th April, and then disappears again. With animals 3082, 3707, 3873, 4026, and 4298, there is no temporary recrudescence of osteophagia. In drawing conclusions from a large number of animals

these idiosyncrasies cancel out, but when the number of animals in a test is small they may vitiate the data altogether. No explanation of individual idiosyncrasy need be offered, however, until more data are obtained in regard to the general influence of age and sex upon osteophagia.

A general consideration of the tables also raises the question of the psychological factor in osteophagia.

Osteophagia is not merely a blind depraved appetite, but a semi-conscious manifestation of the need for something which the animals have probably learned to associate with their healthy metabolism.

Although some animals will continue to eat bones from "habit" for a short time after their craving should have disappeared, they generally abandon the practice the moment their physiological requirements for phosphorus are satisfied. It is true that most cattle will treat sweet sterilized bonemeal as a "delikatessen" and continue to eat it if offered long after osteophagia has been alleviated and the habit of bone-chewing forgotten, but at the same time it is clear that the search for the old bones on the veld is executed in response to some definite physiological need, and is not due to a mere acquired depravity of taste. The acuteness of this need is indicated by the fastidiousness which the cattle display in their selection of available carcass débris. If the craving is very marked (allotriophagia) they will eat stinking half-putrefied bones, or even bits of the flesh itself. If the osteophagia is not quite so acute they will select less objectionable material, while if it is fast disappearing under the influence of the early summer rains upon the vegetation, some of them will hardly take the trouble to pick up even such completely bleached and "sweet" bones as happen to be within reach.

This behaviour, however, was not fully recognized in the early course of the experimental work, nor was the craving so completely identified with phosphorus deficiency as it now is. An experiment was therefore carried out to ascertain whether "depraved appetite" could be satisfied by giving an aromatic electuary. One of the curves in Chart IV, marked "disguised" bonemeal (Table 14 c), indicates the results. When mixed spices (fenugreek, gentian, ginger, and salt) were administered alone, no diminution in osteophagia was effected, but when bonemeal was added to the spices the craving rapidly vanished irrespective of the fact that the flavour of the bonemeal was completely masked. Conversely, crude bone grease is relished by the cattle and is reminiscent of bone, but has no effect upon osteophagia, even when fed in liberal amount (Table 22). In the same way salt does not alleviate osteophagia, and although most cattle show the natural taste for salt many of the worst bone-cravers show the least inclination for it. The appetite for old bones lying about the veld is quite specific, except in the most aggravated cases which are manifested as "allotriophagia" instead of "osteophagia," and presumably the bone-eating custom is developed by the experience of its effect in alleviating craving; perhaps picked up by the more stupid animals, in the first instance, as a trick of the herd. At any rate it is more difficult to induce osteophagia in stable-fed animals on a diet very low in phosphorus than it is to induce it by allowing them to graze over the phosphorus-low pastures with a herd of confirmed bone-eaters. Furthermore, the craving is not manifested towards substances such as sodium phosphate or phosphatic fertilizers which are rich in phosphorus, but which are unpalatable or with which the animals

are unfamiliar. Such substances, however, are equally effective in removing craving, even when the cattle will not eat them voluntarily but have to be dosed with them. This is shown by the later charts on phosphoric acid administration, but also by the curves on the right of Chart V. The corresponding experiments (Tables 18 and 19) were amongst the earlier ones in 1919, carried out at a time when the evidence for the exclusive significance of phosphorus was not so clear, and indeed represent part of the chain of evidence narrowing down the field of inquiry. Bonemeal, bone-ash, "dissolved bones," and "dissolved bone-ash" (superphosphate fertilizer) were compared with one another. Half a pound of bone-ash containing 39 per cent. of phosphoric oxide (Table 10) was found to be nearly as effective as twice the quantity of bonemeal containing rather more than half the percentage of phosphoric oxide (20 to 24 per cent.), the slower reduction of osteophagia being presumably due to the more refractory character of the material after incineration. The similarity of the curves sufficed, at any rate, to exclude the organic matter of bone as a material factor in the alleviation of osteophagia.

Both bonemeal and bone-ash, "dissolved" by treatment with sulphuric acid in converting them into superphosphate, were effective, and would probably be considerably more effective provided they were tolerated by the cattle. The continued diminution in osteophagia following reduction of dissolved bone-ash to 4 oz. per head per day (Table 18) must, however, not be interpreted too hastily, since the acid character of the material, and more particularly the high proportion of calcium sulphate present, seemed to upset the animals. Osteophagia tends to disappear in a sick beast, and since some of the animals sickened, the data must be accepted cautiously. Nevertheless the dissolved bone-ash may be safely regarded as more efficient than the bone-ash itself.

Influence of Non-phosphatic Compounds upon Osteophagia.

In order to ascertain the influence, if any, upon osteophagia of other mineral elements, compounds of calcium, magnesium, iron, sodium, potassium, sulphur, and chlorine were tried. At the same time a few miscellaneous materials were tested, such as whalemeal, sold as a substitute for bonemeal; the disinfectant hycol, sold to the farming community as an internal antiseptic, and by some regarded as a panacea for all the ills that stock-flesh is heir to; finely ground cinders and coal dust, because in aggravated craving cattle do eat cinders and coal scattered about the homestead; bone-oil, sulphur, arsenite of soda, tartaric acid, nitric acid, and condensed milk, for various reasons of definite significance at the time, but of no consequence now.

The data are recorded in Tables 20 to 30, but need not be charted. Of the list of materials concerned, only whalemeal had any noticeable effect, and this simply in virtue of the fact that it contained about half its weight of bone material. Bloodmeal, dominantly protein in composition and containing relatively little phosphoric oxide, was without effect. As would be expected, bone-oil was also without influence. Substances such as sulphur, arsenite of soda, and hycol were quite without effect.

Sodium chloride and sodium sulphate were without influence, although, as will be shown presently, sodium phosphate rapidly reduces osteophagia. Iron sulphate, magnesium sulphate, calcium