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Studies in Demyelinating Diseases of Sheep Associated with Copper Deficiency.—I. "Lamkruis," a Demyelinating Disease of Lambs Occurring in South Africa. II. A Biochemical Investigation on the Incidence of "Lamkruis" in Lambs in the Saldanha Bay, Vredenburg, and St. Helena Bay Environs. III. Experimental Studies, Treatment and Control Measures.

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1. Introduction.

Since 1932, after the publications on the occurrence of "enzootic ataxia" (Bennetts, 1932) in Western Australia and "swingback" (Stewart, 1932) in Great Britain, demyelinating diseases of the nervous system in lambs have aroused considerable interest in various parts of the world.

Recently conditions closely resembling the abovementioned maladies have been reported in other countries, for instance "Swayback", in Queensland (Lee and Moule, 1947) and New Zealand (Cunningham, 1944, 1946) swayback or warfa in Scotland (Dunlop, 1945) and "renguera" in Peru (Tabusso, 1941). Although the aetiology of these diseases is still undetermined, their development in lambs is successfully prevented by adopting copper therapy, during the gestation period of their dams.

In Australia a deficient or low intake of copper is considered to be the primary cause of "enzootic ataxia" in lambs (Bennetts and Chapman, 1937; Bennetts, 1937; Bennetts and Beck, 1942; Bull *et al*, 1938; McDonald, 1932), but in this country there is evidence that "lamkruis" is not necessarily due to a deficiency of this element alone. Liver copper values for ataxic lambs and their dams are constantly low yet corresponding values for apparently healthy lambs from affected properties may even be of a lower magnitude. In this respect our observations are in agreement with those of some of the workers, who investigated the diseases "swayback" in Britain (Innes, 1939; Innes and Shearer, 1940; Dunlop

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et al, 1939; Dunlop and Wells, 1938) and " renguera " in Peru (Tabusso, 1941) respectively. In the latter country this disease occurs in an area in which copper is mined fairly extensively.

In addition the copper content of the vegetation of a healthy locality need not necessarily be of a higher order than that of the herbage in an " affected " area. For instance, in England the copper value of the vegetation of a healthy farm may even be lower than that of the pasture on which " swayback " is apt to occur (Hunter, Eden and Green, 1945). Conversely the copper content of the vegetation of " affected " areas in England (Innes and Shearer, 1940) and Scotland (Dunlop, 1945) and in this country is comparatively of a higher level than that in Australia (Bennetts and Beck, 1942).

It may be reasonably assumed that a low copper value of the pasture and/or a low copper intake need not necessarily be the primary causes of the above mentioned demyelinating diseases of lambs. Nor is a low copper content of the liver of a lamb pathognomonic for " lamkruis ". The possibility of some unknown factor or factors interfering with the proper utilization or metabolism of this trace element by animals in such localities must be considered. In this respect, it has been shown that copper may become less available to the animal in the presence of excess calcium or molybdenum. The deficiency in some cases may, therefore, be only relative and not absolute.

It is a well known fact that the role of copper in haemopoiesis is secondary to its effect on cells in general. As a component of enzyme complexes it exerts a powerful influence on all oxidation-reduction systems, playing, thus, an important part in tissue respiration. Possibly the pathological changes in lamkruis may be the result of defective tissue anabolism brought about by a deficiency of circulating copper or this element may be rendered inert to perform its physiological processes by antagonistic substances occurring in the feed. This may be a new approach in solving this problem.

These diseases, which will be reviewed more fully in a subsequent communication of this series, have a much wider distribution than is usually accepted, and are undoubtedly of such economic importance warranting further investigation. The information so obtained may prove of inestimable value in elucidating the aetiology of demyelinating diseases in the human infant.

The purpose of this publication is to add the disease " lamkruis ", an encephalo-myelomalasia, of lambs occurring in this country to the above list to delineate the area in which the disease has been found, the nature of the malady, some aspects of clinical diagnosis, its possible cause, prevention and treatment.

A detailed account of the pathologic changes will be published in this series at a later date.

Synonyms.

The terms " lamkruis " or " lamsiekte " are applied by farmers in the " strandveld " of the Bredasdorp District, whereas " swaaigat " or " litsiekte " is used in the Saldanha-Vredenburg area.

The names are very descriptive with the exception of " lamsiekte " which is rather vague as it includes other conditions occurring in these areas, such as parabotulism, " domsiekte " or pregnancy disease and " duinesiekte ", a disease comparable with " enzootic marasmus " of adult sheep in Australia (Filmer, 1933; Underwood, 1934).

The popular terms "lamkruis", "swaaigat" and "litsiekte" probably owe their origin to the most noticeable or prominent symptom of the disease, namely paralysis of the lumbar region, which is manifested by a helpless swinging or swaying of the lumbar region and hindquarters and often by knuckling over of the fetlock joint, especially of the hind limbs.

Definition.

"Lamkruis" is one of the most common conditions affecting lambs in some of our coastal areas and is associated with a copper deficiency. It is a non-febrile disease affecting lambs at birth or up to the age of a few months. The characteristic symptom is inco-ordination of movement (ataxia), resulting in frequent stumbling, followed by paresis or total paralysis of the hindquarters and eventually the animal dies in a state of emaciation. Pathologically there is destruction of myelin in the nervous system to a variable degree. A typical degeneration in the spinal cord always occurs and in severe cases symmetrical cavity formation, involving both cerebral hemispheres to a varying extent is seen. The condition may be successfully checked in the progeny of ewes, which had been dosed with or had access to copper supplements during pregnancy.

History.

Although a report on this disease appeared only recently (Landbouweekblad, 1946), there is plausible evidence that the condition is not a new ailment according to some of the older farmers. They have known "lamkruis" for over 20 years and their parents and grandparents were well acquainted with it. Indeed, cases of "lamkruis" were far more frequent in the past than at present. The apparent lack of cases they ascribed to the improved farming and stock-rearing methods and the dosing of their sheep with wire worm remedy or some other copper sulphate preparation.

The first reference to "lamkruis", to our knowledge, appeared in a note dealing with conditions in sheep in the "strandveld" of the Bredasdorp District published in 1930 by Bekker and Rossouw. The disease is characterized by an inability of affected sheep to raise their hindquarters, dragging them when forced to move. As a lack of phosphorus in the soil and vegetation could be demonstrated and the animals in this area were suffering from aphosphorosis (fragility of skeletal bones), the authors assumed that this condition resulted from fractures in the pelvis. Small game (duiker and steenbuck) which abound there are said to suffer from the same condition.

Subsequently in a brief communication, Dunning (1933) described a fatal ataxic condition, "swingback", a disease similar to "swayback" (Stewart, 1932; Innes and Shearer, 1940), in Britain, affecting lambs some time after birth on a farm in the Stellenbosch Kloof. The post mortem revealed no significant lesions, but unfortunately, no special reference was made to changes in the nervous system. The author suspected a nutritional deficiency to be a contributory cause, and mentioned that bone meal feeding, although having a beneficial effect, did not prevent it completely.

Thomas and Malan (1937) who visited the "strandveld" area during 1937 were inclined to corroborate the observations of Bekker and Rossouw (1930) although they had no opportunity of seeing a "lamkruis" case. They suggested that a dislocation of or fracture of the pelvic girdle gave rise to the paretic condition in lambs up to the age of one year, and probably was a complication of a

slow wasting disease in older animals variously termed " lamsiekte ", " duinesiekte ", " bergtering ", or " suursiekte ". The bones of these animals were considerably softer than normal ones and could be broken, bent or cut with ease. Histologically a marked atrophy but no signs of osteomalacia were seen. A mineral deficiency, especially of phosphorus, was suspected to be a complicating factor of the disease.

It is of interest that they recorded a similar paretic condition affecting young bontebok kept in the Bontebok park. The buck become weak in the hindquarters, move with an ungainly gait occasionally swaying behind, get progressively worse and eventually die of malnutrition. None of the affected animals have been known to recover.

During October 1939, du Toit and Schulz (1939) visited several farms in the Willowmore District and in the coastal areas of the Riversdale, Bredasdorp and Swellendam Districts with the object of investigating the cause of several paretic conditions affecting sheep and donkeys and to obtain information to what extent the " trace elements " had a bearing on the aetiology of " lamkruis " in sheep.

As a result of their investigation they concluded that a number of diseases with paretic symptoms affecting sheep and donkeys in different parts of the Cape Province need not necessarily have the same aetiology. " Lamkruis " is a disease very similar to other demyelinating diseases of lambs occurring in other parts of the world. Some relation may exist between lamkruis and duinetering; the former occurring in lambs and the latter in adult sheep. " Duinetering " or " bleeksiekte " may reasonably be compared with " coast " disease (Bennetts, 1940) and enzootic marasmus (Filmer, 1933; Underwood, 1934, Underwood and Beck, 1941), " bushsickness (Underwood and Beck, 1941) and " pine " or " borderpine " (Corner, 1939) affecting ruminants in Australia, New Zealand and Scotland respectively.

During 1941 two of us (van der M. and K. S.) in conjunction with members of the Agricultural Division of the University of Stellenbosch investigated " lamkruis " on a number of farms in the Vredenburg District. On Witteklip, one of the " affected " farms, a flock of 60 pregnant ewes was purchased by the Agricultural Department for this purpose. These animals received no copper supplements, whereas the remainder of the flock (controls) was dosed at regular intervals with a copper sulphate solution supplied by the members of the Agricultural Division, Stellenbosch.

With the assistance of farmers in the vicinity kindly presenting diseased animals gratis, a fair amount of material could be collected for chemical analysis and histological examination. The major part of this article will deal with the salient features of the disease comparatively recently observed, the chemical work which has demonstrated that " lamkruis " is apparently not primarily due to a " copper deficiency ", and with some suggestions regarding its prevention and treatment. The observations made previously (Du Toit and Schulz, 1939) were confirmed and could be appreciably augmented.

Geographical Distributions and Geological Formations of the " Affected " Area.

" Lamkruis ", (" swaaigat " or " litsiekte ") is known to occur on our southern and western coastal areas involving the Knysna, Mosselbay, Riversdale, Swellendam, Bredasdorp, Saldanha-Bay, Vredenburg and Stanford Districts, but as no definite survey of the disease has been made, it is impossible to state with any

degree of accuracy the actual extent of the affected country. Possibly the disease has a much wider geographical distribution than was generally accepted. In this connection the occurrence of a disease " swingback " in lambs on a farm in the Stellenbosch District may be mentioned (Dunning, 1933).

From our investigations it would appear that some areas are distinctly unhealthy, and others quite sound, while others again present an intermediate state. In an " affected " or " unhealthy " area the distribution of the disease may vary distinctly from farm to farm.

In the " Strandveld " lamkruis is more prevalent in the areas where the soil has a cretaceous origin or has limestone outcrops (" Duine " and " Voorduine "), but is absent where the nature of the soil changes to what is known as Rûensveld ". Farmers are apt to refer to the area along the shore consisting of flats and sandy dunes as the " duine "; and dunes are made up largely of crushed crustacean material. The " voorduine " are more inland, are at a higher level than the " duine ", the soil is firmer and is characterized by outcrops of limestone formation. The Rûensveld is further inland, is undulated and the soil has not so much lime. The vegetation on the " duine " consists mostly of grass and is considered to be sweet. On the " voorduine " the grass becomes sparser and is replaced by a variety of low shrub, whereas the vegetation is even poorer on the ruggensveld and has a distinct tendency to become sour. The surface area of Vredenburg* and its immediate environs comprises:—

(1) Dispersed surface lime:—

(*a*) A preponderance of seashell deposits in the near coast belt, and

(*b*) Land shells further away from the coast;

(*c*) Secondary surface lime deposits presumably presenting a transmuted phase of (*a*) and (*b*).

(2) Two young granite intrusions.

(3) Aeolian sand deposits.

The affected area was subjected to two periods of submersion during recent geological times in all probability during the Eocene-Miocene and Pleistocene. In the former period the lime deposits were laid down and during the latter period the land was again submerged to a depth of 100 feet or more below the present sea level. The lime deposits formed during the Eocene-Miocene were eroded to a marked degree, leaving typical terraces when the sea receded. Deposits of both calcium phosphates and iron-aluminium phosphates are distributed throughout the affected area.*

On the south coast the " affected " strip stretches from close to Knysna westwards, and varies in width up to approximately twelve miles in places. The soil in this region is of a calcareous nature, consisting of calcareous blown sands and consolidated limestone formations probably of recent origin, the sand often covering the limestone beds. At irregular intervals this strip is broken by sandstone formation running right down to the sea or alluvial and other soils cover the calcareous deposits. In this area the incidence of lamkruis seems to be closely correlated with the calcareous soils.

On the west coast the occurrence of lamkruis was found to be very pronounced in the Saldanha-Bay-Vredenburg Area. Here also the incidence was greatest on the calcareous soils (calcareous sands and limestone formations), but was also

*Personal communication by Dr. F. C. Truter, geologist, Pretoria.

found to occur on farms with an admixture of soils of a calcareous and red granite origin. Much further south in the Stellenbosch District, lamkruis was found to occur where the soils are mainly of granite origin.

Epizootology.

Although the vegetation along the coast is fairly luxuriant during the rainy season and is considered sweet, it becomes exceedingly sparse after the dry season has set in. During the latter period the feed is not only unbalanced in regard to protein, and carbohydrates but was deficient in other respects also. Protein was qualitatively deficient, vitamin A practically absent and a mineral deficiency, especially of P is a serious limiting factor in stock rearing in the Bredasdorp " Strandveld " area. The P deficiency is complicated and accentuated by at least two factors, e.g. protein deficiency and food scarcity (Thomas and Malan, 1937). Stock rearing cannot be carried out here successfully. Horses contract " beensiekte " (osteofibrosis), cattle develop " heupsiekte " (hip disease) and a disease resembling " Falling Disease " of cattle in Australia (Bennetts *et al.*, 1941a, 1941b, 1942), and lambs become affected with " lamkruis ". Older sheep become unthrifty, their wool becomes " stringy ", and they die of malnutrition if kept continuously on such veld. This last condition is known by several names such as " Duinesiekte ", " Duinetering ", and " Bleeksiekte ". As suggested this condition and " lamkruis " may have a common cause (Thomas and Malan, 1937; Du Toit and Schulz, 1939). In this area young pigs are sometimes paralysed in the hindquarters; but the cause of the disease could not be determined.

As a rule affected lambs may be born from ewes of all ages, but on some farms, the older ewes, reared on the " affected " area, were more prone to do so. Presumably they are not carriers of " lamkruis " as it does not follow that once an ewe has produced a " diseased " lamb she will always do so. Either sex may be affected with " lamkruis " and while many lambs are diseased at birth, symptoms appear in others only after a period varying from a few days to weeks and even months.

General Incidence.

The disease in confined to the progeny of ewes which have been pastured continuously for several months on " affected " farms. There is no evidence that it spreads to healthy districts despite transfers of stock from affected areas. As in other parts of the world where demyelinating diseases occur in lambs, it forms one of the most serious diseases of sheep in the coastal areas mentioned above. Some farmers asserted that if the dosing of sheep with copper sulphate was neglected, the mortality would be as high as 80 to 90 per cent. of the total lamb crop on badly " affected country " (Du Toit and Schulz, 1939). The incidence, however, varies considerably on different farms in a " lamkruis " area, and is even known to vary on the same farm from year to year. In some flocks only a few cases may occur, in others the percentage of animals affected varied from 10 to 50 per cent., and in exceptional cases the incidence may be as high as 90 per cent. If certain measures, enumerated below, are adopted, the number of cases is considerably reduced on " affected " country. It would appear that, since lands have been cultivated more intensely to produce higher wheat crops and the sheep dosed more regularly with wire worm remedy or other preparations containing copper sulphate, the disease has become less prevalent. By changing the grazing periodically from strandveld to rûensveld or *vice versa* in the Bredasdorp, Riversdale and Swellendam Districts, the number of " lamkruis " cases is reduced to a minimum. Therefore, most farmers who can afford it have " wisselplase ", i.e.

farms situated outside the affected area to which the sheep can be moved during the year. However, difference of opinion still exists as to whether sheep should be allowed to lamb on the strandveld or on the rûensveld. Another procedure to prevent any serious losses is to purchase fresh breeding stock, usually from the Karroo, each season or two. The introduced animals should not be younger than two tooth and should not be kept on the affected farms too long before the lambs are dropped. On some farms sheep rearing has been discontinued, and only hamels are kept on these properties. After two to three wool crops have been obtained, the sheep are fattened and sold to the butcher for slaughter (Du Toit and Schulz, 1939). In the Saldanha-Vredenburg area the procedure is to move sheep from "affected" farms to the "Swartland" (Malmesbury and Darling Districts) for several weeks prior to lambing.

Climatic Influence and Seasonal Variation.

There is evidence that climatic and seasonal variations have at least some influence on the prevalence of the disease. It was recorded that during cold and rainy spells at the beginning of June, 1941, the mortality in lambs of untreated ewes on the farm Witteklip was considerably higher than that in lambs of the control flock. However, towards the end of June under similar unfavourable climatic conditions there was no appreciable difference in the losses of the two flocks. It would appear that "lamkruis" lambs are more susceptible to exposure at the beginning of the lambing season than later. Cases of lamkruis, according to the farmers, are far more prevalent after a very dry summer than after a less droughty one. There is no definite seasonal occurrence; lambs born at any period of the year may develop the disease; however, more lambs are affected at the beginning of the lambing season with lush growth of pasture than towards the latter part when the vegetation is less luxuriant. It may well be thought strange that most cases occur at a time when there is actually an excellent growth of pasture, but, if the intra-uterine origin of the disease is borne in mind, the state of vegetation during the greater part of the gestation period should be considered rather than that at the actual time of lambing. In the "lamkruis" areas, with a winter rainfall, mating of the ewes takes place from November onwards and the whole or part of the gestation period falls within the dry summer months. Now, as a result of the prevailing arid condition, the increasing scarcity of food leads to cachexia and a marked nutritional deficiency in the sheep, especially in the pregnant ewes which may reach its climax at the time the rains set in. This state may often be accentuated by a heavy worm infestation. The lambs, thus, dropped early in the lambing season, which incidentally coincides with the onset of the rainy season and a marked improvement of the vegetation, are more likely to be born with ataxic symptoms than those born later when the pasture is less luxuriant. Possibly the mothers of the latter lambs have had an opportunity of improving their condition while gestating and possibly the factors responsible for the malady could have been partially or totally eliminated. It seems feasable that the incidence of the disease would be much higher after a very dry summer than after a less severe one. An interesting observation which seems to bear out this contention has been made by Bennetts and Beck (1942), in Australia. Experimental evidence led them to believe that, in general, ewes in good strong condition at the beginning of the gestation period are less likely to produce ataxic progeny than those in poorer condition.

It would appear, therefore, that climatic and seasonal variations may indirectly influence the prevalence of the disease and are predominently responsible for the variations in the yearly incidence.

Breed Incidence.

" Lamkruis " affects all breeds of sheep in the district. The disease has been observed in Merinos, blackhead Persians, bastard sheep and in the progeny of these breeds and their crosses sired by karakul rams. The number of cases was too small to state definitely whether one or other of the breeds was more susceptible to the disease.

Species Incidence.

The disease " lamkruis " is confined to lambs but sometimes affects kids also. On some of the farms in the Vredenburg-Saldanha Bay Area on which " lamkruis " is known to occur, young pigs at the age of a few months may develop a posterior paralysis. The aetiology of this condition remains undetermined as no material was obtainable for histological or chemical examination. Adult cattle in this area (farm Geelbek) may be suffering from a wasting disease characterized by anaemia. From the data at our disposal the condition may be associated with a copper deficiency (Truter and Schulz).

Age Incidence.

Lambs carried to full term may be still-born or may die shortly after birth without any apparent reason. In " lamkruis ", however, most of the cases are affected at birth and some show symptoms a few days to several weeks later, whereas " enzootic ataxia " is not often seen in lambs before they have reached the age of from 3 to 6 weeks and generally not later than at four months, the time of weaning. (Bennetts and Beck, 1942). *As in man one can assume that demyelinating diseases in lambs have either a congenital or post-natal origin.*

Hereditary Influences.

From our investigations it would appear that " lamkruis " is not hereditary in nature. There is conclusive evidence that " swayback " or " warfa " is not a hereditary disease. Cases have been recorded where slightly affected ewes nursed perfectly normal and healthy lambs.

Economic Importance.

The exact economic importance of " lamkruis " is difficult to assess, as the actual distribution of the disease in this country is still unknown. However, the losses sustained each year as a result of this disease must be considerable, if the high mortality of lambs, the decreased value of the " stringy " wool, the expenses involved in moving the sheep to better grazing and the periodical purchasing of fresh breeding stock are considered. In addition large tracts of coastal and semi-coastal country are totally unsuitable for sheep rearing and proper development is restricted. As the administration of copper supplements to sheep in these areas has proved an efficient prophylactic for " lamkruis " and incidentally is responsible for a better condition of the sheep and growth of wool, it would appear that these vast tracts should be capable now of great development.

Symptoms and Course.

The symptoms and course of " lamkruis " may vary considerably in the affected animals. Three distinct types of " lamkruis ", a congenital, a " delayed " or " chronic ", and a post-natal, may be distinguished. The former type is noted at or shortly after birth of the lamb. Such an animal may lie prostrate on the ground or is recumbent in the sterno-abdominal position, being unable to rise or suckle, although it appears otherwise apparently normal. The head is either held erect

with occasional swaying movements, or it is bent round to one side. An apparent loss of control of the hind limbs is manifested by limpness and abnormal positions of these extremities which are not drawn up towards the belly as usual. A few affected lambs, after spasmodic efforts to rise, can get on to their feet with some assistance; others may rise unassisted, but fall down after a short time. The characteristic symptoms are muscular inco-ordination, impaired movement and general weakness of the hindquarters, (figs. 1 and 2). In the more severe cases an animal has a peculiar stepping action, may lose its balance, turns somersaults, falls on to its side and makes agitated paddling movements with its legs, but is unable to rise unassisted, (fig. 3). Occasionally a lamb may struggle along on its fore-limbs, dragging its hindquarters helplessly along the ground, or it may take up a sitting position (fig. 2). The appetite remains unimpaired, but as the disease progresses the affected animal lags behind its mother, loses condition and may eventually die of starvation. The loss of condition must be ascribed to the inability to suck and graze normally. Such an animal may live for several days, but as no improvement is attained even if it is hand fed, the farmers are apt to destroy all the lambs showing signs of disease.

FIG. 1.—Affected lamb showing impaired movement and general weakness of the hindquarters.

FIG. 2.—Affected lamb in sitting position.

FIG. 3.—Affected lamb, 3-4 months old after it fell on to its side. Stilbaai area, 1939.

In the " delayed " cases, apparently normal at birth, the malady develops within a few days or even weeks, and a more typical picture of " lamkruis " is seen. Such lambs exhibit varying degrees of locomotory weakness from complete ataxia to unsteady gait; there is a distinct drooping of the croup and the hind legs are held wider apart than usual during standing and walking. The gait is stiffer than normal and the hind feet may be dragged along the ground. Excitement of any kind greatly aggravates the symptoms. An affected animal urged to move faster, especially over uneven ground, " knuckles over " at the pasterns, with sagging and swaying of the hindquarters (fig. 1) and eventually the animal falls on to its side (fig. 3). After a period of rest the animal is able to rise and to move about again. Some animals develop a peculiar " bobbing " action when forced to run. During the act of running the hind legs are drawn up together and on striking the ground the hindquarters shoot up as if from a springboard. The condition may become progressively worse, ending in permanent prostration, and the lamb dies usually within a few weeks in a cachectic state, or falls a victim to myiasis, or some intercurrent infection. In no case could a rise of temperature be recorded, except in animals which were suffering from pneumonia. There is no loss of sensation in any part of the body, and no hyperaesthesia. The word paralysis has been used in a somewhat loose sense. *There appears to be no definite loss in power but an apparent interference with or total lack of control of the hind limbs.* An affected lamb raised from the ground is capable of carrying out vigorous kicking movements even although it is unable to rise from the ground. *As there is no loss of power of movement or sensation, the syndrome should be merely regarded as an incoordination of muscle* (*ataxia*), *true paralysis being absent.* A similar conclusion was arrived at in the diseases " swingback " or " swayback " and " enzootic ataxia ". Muscular tremors and frequent acts of urination are noted in a few " lamkruis " cases. A number of lambs, especially those with slight symptoms and which survive for several weeks, commence to thrive and apparently recover, but retain a degree of ataxia for a considerable time even after they have been moved to better grazing (Du Toit and Schulz, 1939). A striking feature of the disease is that on some occasions the lambs appear to be in perfect health and make excellent growth, yet when the flock is driven fairly fast for some distance, quite a large percentage of lambs and adult sheep may be found to be ataxic (Du Toit and Schulz, 1939). The affected animals lag behind the others. Farmers trekking with sheep in this area are forced to rest the sheep after they have been moved for comparatively short distances.

Those cases developing later in life must be looked upon as post-natal cases and need not necessarily be associated with " lamkruis ".

In the affected areas interesting observations were made on unsound fleeces exhibiting characteristic changes described as " straight " or " hairy " wool. The wool fibres lose their crimp and have a limp, glassy, and straight appearance. The condition improves either when the grazing of the sheep is changed or when copper supplements are administered regularly to the animals. This condition has been studied by some members of the staff of the Stellenbosch University and a full report of their investigation will be published. It is of interest that a similar condition has been described in Western (Bennetts, 1942) and South Australia (Bull *et al.*, 1938; Inform Circ. S. Aust.), New Zealand (Cunningham, 1944, 1946) and Queensland (Lee and Moule, 1947). The unsoundness of the wool is known as " stringy ", " straight ", " steely ", and " silky " or " galvanized " respectively, and is associated with a copper deficiency in sheep. Similar changes in wool have not been published in England. Possibly no one with experience of wool grading has ever seriously considered this factor, or the type of sheep may not show this change.

Anatomical Pathological Changes.

Macroscopic changes.—The external appearance of the body varies with the course and the stage of the disease at which the examination is made. In most cases, which may be regarded as acute or milder chronic ones, no significant changes were present, there may be relatively little evidence of malnutrition and no signs of anaemia. In the older animals some degree of malnutrition and evidence of retarded growth is almost invariably present. Gross muscular atrophy was, however, never observed. Some of these cases are affected with myiasis, and in a stunted lamb the thymus was considerably reduced in size. No characteristic lesions were found in the internal organs of any one of the affected lambs, except in a few moderate fatty degeneration of the liver and kidney and in those with a secondary infection of the respiratory tract, a bronchopneumonia were diagnosed. In one sheep the colour of the pancreas was dark orange similar to that described in " coast " disease (Du Toit and Schulz, 1939). On no occasion was an enlarged thyroid present, nor were any signs of recent or healed fractures in the skeleton encountered, or was any lamb found to be infested with ticks.

The macroscopic lesions of the central nervous system may also vary considerably in different animals. The degree and extent of the changes need not necessarily parallel the severity of the clinical symptoms recorded.

In some of the animals lying prostrate after birth no significant macroscopic lesions may be noted, while in others with less pronounced symptoms areas of softening and fairly extensive cavity formation are seen in the cerebral hemispheres. Usually, however, the most extensive lesions occurred in affected lambs killed shortly after birth. As a rule no macroscopic lesions were found in the cerebrum of the older ataxic animals, but in one case, a lamb 3 to 4 months old, comparatively small cavities involved some of the convolutions of the parietal lobes (Du Toit and Schulz, 1939). A striking feature of the pathological changes in acute cases is their symmetrical distribution chiefly confined to the white substance of the cerebral hemispheres.

In a fairly large number of cases no abnormalities were observed in the brains; the grey and white matter was well preserved, clearly demarcated and appeared

normal in amount and distribution. In all cases no changes could be detected by a cursory examination of the cerebellum, hypophysis, medulla, choroid plexus, and the whole spinal cord and peripheral nervous system.

A more detailed account will be published at a later date and will serve further to illustrate the divergence of the morbid changes in the central nervous system of " lamkruis " cases.

Histology.

Viscera.—Apart from fairly extensive fatty changes in the liver and kidneys, degenerative changes and haemorrhages of varying extent in the adrenals and degenerative changes in the lymph glands of some animals, no significant lesions were observed in the visceral organs examined of affected animals. As the pathological changes enumerated were not constantly present too much importance cannot be attached to them. *The costo-chondral junction* appeared normal in the young animals, but in the older ones slight signs of atrophy were present.

Musculature.—Slight to fairly marked diffuse fatty changes were confined to several fibres of the semitendinosis, semimembranosis and psoas muscles of some of the older lambs but these changes were not present in the muscles of any of the young affected ones. Other muscles were, however, not collected and of the above-mentioned only a limited number have been examined. The fatty changes cannot be considered a constant feature of the disease.

Nervous System.—The histological changes in the nervous system vary considerably in animals affected with " lamkruis ". The variations are more marked in the acute (severe) than in the chronic milder cases. The lesions are described in fair detail below.

Brain.—No constant lesions were observed in the brains of diseased animals. When noted their intensity varied from slight (marked congestion) to severe (cavity formation). All gradations varying from congestion of the bloodvessels, oedema of the brain substance, and foci of softening of the white matter, to extensive cavity formation may be recognized in severe cases, whereas in a less marked case any one or several of the enumerated changes may occur. In some, however, especially in the older lambs, there were no apparent changes.

A striking feature of the acute disease is that the most pronounced lesions are usually confined to the white substance of the cerebral hemispheres, but exceptionally the cortex may be involved (Du Toit and Schulz, 1939). The nature of the lesions in the cortex was that of a coagulating necrosis, whereas a colliquaceous necrosis (intravitam autolysis) involved the white matter of the subcortex. Demyelination and loss of axis cylinders lead to cavity formation, which may vary considerably in extent. In the most severe cases the central white matter is reduced to a thin subcortical layer around the cavity (fig. 4 and 5). Rarely do the lesions extend into the deeper cortical layers. In the milder cases, as a rule, no distinct cell changes were recognized in any part of the cortex, midbrain or brain stem; the cells retaining their normal form, arrangement and structure in spite of changes in the white matter. Where gross demyelination of the hemispheres is present, however, there is a distinct derangement of the architectural structure of of the cortical layers manifested by an apparent reduction of the pyramidal cells and a definite increase in the other nerve cell elements. Degenerative changes of varying degree and even calcification occur in the remaining pyramidal cells.

Spinal Cord.—Characteristic lesions were constantly present and consisted of degeneration of the myelin sheaths of nerve fibres particularly in the periphery of the cord. The degree of degeneration and the proportion of fibres affected varied; apparently a more diffuse distribution occurs in acute cases (fig. 6). By applying Marchi's method to sections of the cerebrum, cerebellum, medulla, and portions of the cervical and lumbar spinal cord of older lambs and adult sheep slight or no changes could be demonstrated, whereas changes became apparent in some sections after the use of the Weigert-Pal stain. As in the case of the brain there was no evidence of any inflammatory reaction.

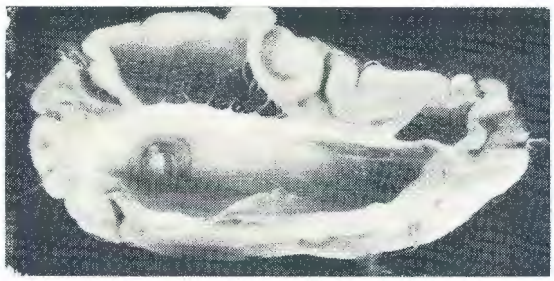


FIG. 4.—Longitudinal section of cerebrum of an affected Karakul cross female lamb, a few hours old. Note network in cavity. (Vredenburg area.)

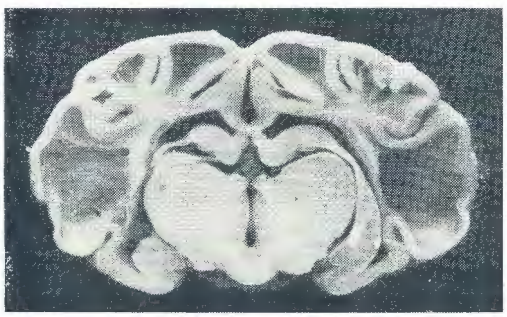
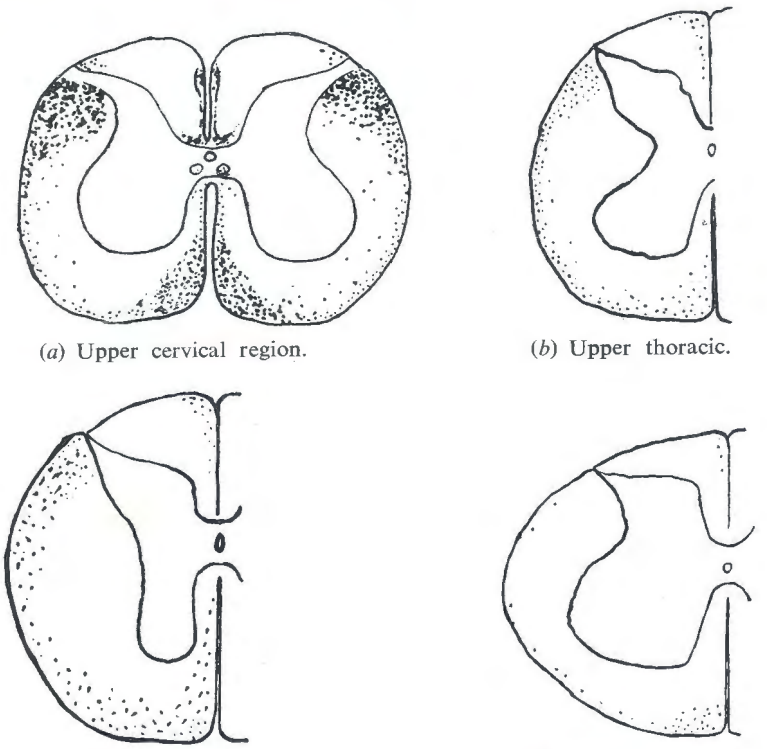


FIG. 5.—Cross-section of brain of an affected lamb. Note marked cavity formation in cerebrum.

Peripheral Nerves.—In only a limited number of cases were the sciatic nerves and their branches and the femoral nerves examined for degenerative changes in the myelin sheaths. The degree of degeneration and proportion of fibres affected varied. The changes could be classed as very slight, slight and fairly distinct in some fibres. No inflammatory changes were demonstrable in Giemsa-stained sections.

Diagnosis.

The disease as far as is known at present, occurs only in certain confined areas in the Knysna, Mossel Bay, Riversdale, Swellendam, Bredasdorp, Saldanha Bay, Vredenburg and Stanford Districts, and in typical outbreaks of the disease the diagnosis will present no difficulty as the general features of it are highly characteristic.



(*a*) Upper cervical region. (*b*) Upper thoracic.

(*c*) Lower thoracic. (*d*) Lumbar region.

FIG. 6.—Schematic drawings of various portions of spinal cord. Note progressive increase of lesions from lumbar to cervical region.

Differential Diagnosis.

A number of ataxic diseases affecting lambs at the time of birth and some time afterwards are known to occur in various parts of the world, but they can be differentiated from lamkruis with comparative ease.

1. *A Disease in Newborn Merino Lambs Affecting the Thyroids and Nervous System.*—This condition occurred in new-born merino lambs on some farms in the Thaba'Nchu, Brandfort (Williams *et al* 1938), and Reddersburg Districts (Kellerman and Schulz), in the Orange Free State, and the characteristic signs were markedly enlarged thyroids and nervous symptoms manifested by pronounced weakness or inco-ordination of movements of the hind limbs. The mortality among the affected lambs was excessively high, almost 100 per cent. of the lambs dying from within a few hours to a few days after birth. The symptoms of ataxia may still be detectable up to 3 weeks after birth, a period considerably shorter than that recorded for " lamkruis " (6 months or even more). The disease is prevented if pregnant ewes have access to green grazing one or two months prior to lambing and the incidence is reduced if green feed was supplied to them after the first lambs were dropped. Contrary to the experience of lamkruis by taking the lambs as soon as possible after birth from their mothers and hand rearing them on cows milk a number of lambs recovered and continued to make good progress. (Kellerman and Schulz.) Of the two lambs that were brought to Onderstepoort

and fed on cows milk, one died a few days later but the other made a complete recovery after some weeks. Figs. 7 and 8 show the lamb before and after treatment, respectively. As far as could be ascertained the disease was the result of the prolonged grazing of the pregnant ewes on very poor, dry, mature grass pastures deficient in substances (vitamin A, phosphorus, protein, etc.) of vital importance for normal growth and maintenance of health. Corroborative evidence for this presumption was obtained by producing a similar condition in new-born lambs whose mothers received a ration deficient in phosphorus and vitamin A (Williams *et al.*, 1938).

FIG. 7 (*a*).—Lamb with enlarged thyroid from a farm in the Orange Free State. Note lack of tension in muscles. (Front view.)

FIG. 7 (*b*).—Same lamb (side view) being fed with cow's milk.

FIG. 8 (*a*).—Same lamb after 3 weeks, markedly improved. (Front view.)

FIG. 8 (*b*).—Same lamb. side view. Note straightening of limbs.

2. *Stiff-lamb Disease or White Muscle Disease.*—Stiff-lamb disease is a non-febrile ailment of young suckling lambs, the trouble usually becoming apparent a few days after birth or when the lambs are 1-5 weeks, 2-8 weeks, or 3-10 weeks old, and affects lambs of ewes confined in pens or sheds on a restricted diet and lack of exercise (Metzger *et al.*, 1927; Willman *et al.*, 1934; Vawter *et al.*, 1939). The yearly incidence may vary considerably from 10 to 15 per cent. (Metzger *et al.*, 1927). Although this disease may cause heavy losses in one year, it may have a low incidence in the following year. The characteristic lesions, occurring chiefly in the muscles, appear as whitish areas to the naked eye. There is a

bilateral symmetry of lesions as almost invariably the same muscles on the two sides of the body are equally affected. On microscopic examination there is a considerable variation in the amount of degenerative changes, whole bundles and even whole muscles may be involved. The bilateral symmetry of the lesions suggests the involvement of the central nervous system, but all attempts to find positive indications of lesions in the brain, spinal cord and nerve trunks have failed. The factors contributing to the occurrence of the disease are still obscure but an insufficiency of phosphorus or Ca:P ratio may be involved, as lambs of ewes receiving a diet higher in phosphorus than others did not develop the disease. Recently, however, the disease has been linked with a vitamin E deficiency (William *et al.*, 1945). The term " stiff lambs " embraces several separate diseases and infections such as those caused by *Actinomyces necrophorus, Corynebacterium pyogenes, Erysipelothrix rhusiopathiae,* and *Clostridium tetani.*

3. *Tick Paralysis in Lambs.*—This disease appears to have a seasonal occurrence and is apparently the result of a *Rhipicephalus evertsi* infection (Clark, 1938). An outstanding feature of this disease is that, although this type of tick is very prevalent on all the sheep the incidence of paralysis is low. The condition appears suddenly and may disappear rapidly; complete recovery being achieved by removing the ticks from the affected animals. The disease can be easily differentiated from lamkruis if its lower incidence and the increased age, 9 months to one year at which the lambs become affected, are considered. However, in 1948 lambs at the age of 5 days, infected with the paralysis tick (*Ixodes rubicundus*), showed either ataxia or total paralysis (Theiler and Schulz, 1948). The presence of one tick may cause the disease.

4. *An Enzootic Staphylococcal Infection* has recently been described in young lambs on tick-infested farms in Britain (McDiarmid, 1948). A characteristic impairment of joint movement was noticed together with inco-ordination of gait, which could be attributed either to the joint lesions or to involvement of the meninges in a suppurative process. A rise in temperature and even a subnormal temperature prior to death was recorded. At the height of the febrile reaction blood from some lambs gave cultures of *Staphylococcus aureus.* A common post mortem feature of the disease was abscess formation in all cases.

5. *An Enzootic Corynebacteria Infection.*—During April, 1948, a febrile disease, affecting lambs at the age of one to two weeks and characterized by impaired and inco-ordinated movements, was reported on the farm Allendale, Graaff-Reinet District, by Dr. Belonje, Government Veterinary Officer, Middelburg, Cape. The condition could be ascribed to a corynebacteria infection causing disseminated necrotic myositis of the chief locomotory muscles of the fore and hindlimbs. In addition a non-purulent encephalitis, most pronounced in the cerebellum, could be demonstrated histologically (K.S.)

6. *Coenurus cerebralis Infection.*—This parasite was found in a goat, showing nervous and paretic symptoms, and a fair number of lambs (under one year old) with locomotory disturbances (possibly also infected) were seen on a farm in the Willowmore District (Du Toit and Schulz, 1939). The disease usually affects sheep at the age of one year, but exceptionally cysts may occur in lambs a few days old (Simonds, Hering). An intra-uterine infection with oncospheres in the latter cases is suggested.

7. *Staggers in Sheep in Patagonia.*—The disease affects lambs and hoggets under one year old and adult sheep to some extent (Jones and Arnold, 1947). It is characterized by a nervous disorder. The disease is not confined to the ovine species alone; horses and cattle succumb readily to it. Staggers is unknown in flocks grazing between pampa and sea.

8. *Fern Poisoning in Texas.*—The disease is popularly named " jimmies " and has been produced experimentally in sheep, goats and cattle by feeding the fern, *Notholaena sinusata var. crenata* (Mathews, 1942). It is characterised by nervous symptoms such as trembling. Affected animals may die when forced to move. Toward the end of the season the members of an affected flock lack co-ordination of movement in all fours. The hind limbs cannot keep up with the force ones with the result that the animal falls with the hind limbs back and fore limbs forward.

9. *Slapsiekte of Lambs.*—This disease affects lambs and donkeys (Du Toit and Schulz, 1939) on properties in the Willowmore District on which " kaalsiekte " (Steyn, 1931) is also very prevalent. The symptoms noted bear a marked resemblance to those described under the former heading, i.e. the affected lamb falls with the hind limbs stretched posteriorly (fig. 9), and figure 10 shows an animal that has recovered after it had been placed on a lucern patch.

FIG. 9 (*a*).—Sheep with paresis on a farm, District Willowmore, 1939.

FIG. 9 (*b*).—Same sheep after it fell to the ground. Note hind limbs extended backwards.

10. *An enzootic paraplegia* has been described in France (Aychet, 1938), accompanied with heavy losses, as a result of toxic enteritis. The disease occurs in lambs two to six weeks old, however, never in lambs of the milk types. It is not a parasitic nor an infectious transmissible disease, but a toxaemia, resulting from

intestinal bacteria. The musculature, chiefly of hindquarters, shows a salmon coloured or greyish striped degeneration. A nultritional deficiency is suspected, for instance milk deficiency of the ewe, wrong diet (turnips) and intestinal catarrh.

FIG. 10.—Another sheep from the same farm placed on a lucerne plot. Recovered, 1939.

11. "*Cripples in lambs* (Stewart and Lyle, 1933; Piercy, 1934) is a disease of well-nourished lambs from the age of seven to fourteen days characterised by muscular stiffness, inability to flex the joints, and by abnormal fragility of long bones and ribs, resulting in their frequent fracture. The symptoms are probably related to imperfect osteogenesis, causing the formation of a type of bone deficient in quantity and/or abnormal in character. Changes of "white muscle" disease occur in the muscle of lambs which have lain on the ground for 5 or 6 days (probably secondary in nature).

12. "*Malkop" in Lambs.*—During April of 1948, Dr. Belonje, the Government Veterinary Officer of Middelburg, Cape, reported a disease of lambs, locally known as "malkop" occurring on the farm Redlands in that district. The term is probably ascribed to the irrational behaviour seen in affected lambs. The condition is characterized by muscular inco-ordination; the lamb sways as it walks, being weak in the hindquarters. There may be perpetual throwing back of the head and animals with such symptoms were unable to walk in a straight line. Lambs may become affected from birth up to the age of 3 weeks. Apparently only a small percentage of lambs become affected. The histological examination of the central nervous system revealed a meningo-encephalo-myelitis. Pronounced nephrosis, areas of hyalin degeneration in the muscles of the hindquarters and disseminated foci of myositis as described under "stiff lamb" disease were also seen (K.S.). The cause of the disease could not be determined.

"*Aetiology*" *of Lamkruis.*

Although no cultural methods were carried out and no attempts were made to transmit the disease by subdural inoculations of suspensions of brain and spinal cord of affected lambs into susceptible ones, there is sufficient evidence to exclude a virus or bacterial infection as a likely cause of the disease. In no case could a febrile reaction be recorded and pathologically there was no evidence of an inflammatory reaction in the central nervous system that could be associated with a virus or bacterial infection. On no occasion could inclusion bodies or other signs (perivascular cellular infiltrations) usually associated with a virus infection be

demonstrated. Neither were any joint lesions nor affections of the muscles indicative or bacterial invasions present. It may be reasonably assumed that the disease is not of an infectious or contagious nature; normal lambs kept in close contact with diseased ones never became affected.

A toxic substance either of vegetable or mineral origin in the ewes' milk has been suggested, but lambs suckled on ewes which had dropped lamkruis lambs did not contract the disease. Apparently the causal agent was either not excreted by the milk of the ewe as has been previously suggested for enzootic ataxia (Bennetts, 1935), or was present in such small quantities to have no hazardous results. Lamkruis could not be associated with a poisonous plant or fungus infestation of the pasture. Whether lead is a contributory cause can not be stated at present, since this factor has not received attention in the past.

The strictly regional occurrence and the beneficial effect that change of pasture has on the incidence of the disease strongly suggest a nutritional origin. The possibility of a vitamin deficiency as a likely cause or as a complicating factor cannot be definitely excluded, if the nature of the feed during the whole or part of the gestation period is considered. However, an avitaminosis A or a lack of vitamin E may be eliminated as likely causes, since the characteristic lesions of these affections (mentioned above) were not demonstrable in the material examined of " lamkruis " cases. Vitamin B should receive more attention in the future, since feeds lacking in this ingredient may give rise to affections characterized by demyelination in the nervous tissue.

An aphosphorosis as a contributory cause has been suggested in the past (Bekker and Rossouw, 1930; Dunning, 1933; Thomas and Malan, 1937) but one of the authors (Dunning, 1933) has pointed out that, although bone meal feeding had beneficial effect, its use did not prevent the occurrence of " swingback " of lambs in the Stellenbosch District and that some other factor must be involved. Evidence was produced (Du Toit and Schulz, 1939) substantiating this latter supposition, indicating that " lamkruis " was associated with a copper and not a phosphorus deficiency. The paralytic condition formerly ascribed to fractures or dislocation of the pelvis has nothing in common with this condition under discussion. The lambs did not suffer from fragile bones and it was shown that the bone structure of a " lamkruis " lamb did not differ from that of a normal lamb of the same age. The term " lamkruis " should therefore not be used in those cases resulting from fragile bones. The results of our investigation corroborate the above conclusion. It could be demonstrated that " lamkruis " is not primarily caused by a copper deficiency and a lack of phosphorus is probably not a contributory cause as the animals (sheep) in the Saldanha-Bay area do not suffffer from an aphosphorosis. Corroborative evidence was produced by examining the costochondral junctions of older sheep, the bony structure of which being apparently normal.

The exact role that copper plays in the aetiology is not understood, but possibly it forms a link in a chain of contributory causes. We are not inclined to believe that the demyelinating process which occurs in this disease can be reasonably explained by a mere copper deficiency. The aetiology of lamkruis still remains obscure but there is evidence indicating that the lesions are of a vascular and/or circulatory nature, presumably as the result of functional disturbances, which are known to produce similar changes in the central nervous system of the human being (Josephy and Lichtenstein, 1943). Abnormal products may be formed which may further accentuate the morbid changes in the involved areas. Attention is drawn to a nutritional encephalo-malacia of chicks in which

the earliest and mildest recognizable lesions point very definitely to a circulatory disturbance as the initial factor in the production of the lesion. In this disease, however, the changes are briefly confined to the cerebellum, but the cerebrum, medulla and midbrain may also become involved (Wolf and Pappenheimer, 1931), as a result of the disturbed metabolism.

Pathogenicity.

No other animals except lambs (principally) and goat kids develop typical symptoms of " lamkruis " in the " affected " areas. The disease is seldom if ever noticed in the young of indigenous buck which may probably be accounted for by the change of pasture sought by the does (Thomas and Malan, 1937). However, a paretic condition has been observed in game (young bontebok figs. 11 and 12) duiker and steenbuck and young pigs in these areas. Fullgrown sheep are not susceptible, but even healthy lambs do not contract the disease when in close contact with affected ones. The adult sheep showing signs of the disease may be considered either to be incompletely recovered cases or cases resulting of a fractured or dislocated pelvis in sheep grazing on the Strandveld-Bredasdorp District.

FIG. 11.—Bontebok paralysis, Bontebok Reserve, Bredasdorp, 1936.

In some of these coastal areas an emaciation of sheep and young cattle (duinesiekte) has been noticed and diseases such as paratyphoid in calves and " broken wind " in draught animals (called " ruksiekte " or " benoude bors ") and " bighead " or osteofibrosis of horses may be very prevalent. In addition, owing to the softness of bone and its increased fragility, fractures of the pelvic bones are apt to occur giving rise to diseases locally known as " heupsiekte " (fig. 13) and " lamsiekte " in cattle. Fairly recently a disease similar to " Falling Disease " in Australia has been observed in cattle grazing on pasture of the Saldanha-Bay area. The possibility of greater susceptibility of animals to diseases under conditions prevailing in these coastal regions is a problem that requires further investigation.

FIG. 12.—Bontebok showing paralysis. Bontebok Reserve, Bredasdorp, 1936.

FIG. 13.—Cow with „Heupsiekte" (fractured pelvis) Strandveld, Bredasdorp area, 1939.

Pathogenesis.

There seems to be no doubt that a large number of cases develop intra-uterine, the so-called congenital forms, which show symptoms just after birth or some variable time later. It is well-known that clinical symptoms may appear only some time after the nervous tissue become affected, thus some of the latter

forms may possibly be " delayed " cases. However, depending on the age at which the animal becomes affected, the occurrence of post-natal cases may be readily assumed. Thus the pathogenesis will vary in the different types, although the end results may be identical.

At this stage of the investigations it would not be quite futile to speculate about the possible mode of development of " lamkruis ". But so long as the aetiology remains obscure there is little hope of definitely solving the pathogenesis. Our knowledge so far is mainly of a negative character. There appears to be definitely no infection by contact. Copper is not the primary cause, but probably only one of a number of contributory causes. The lesions are definitely not due to birth trauma, nor can they be associated with plant poisoning or fungus infestation of the pasture.

A striking feature is that the dams of such affected lambs are apparently clinically healthy. For this reason formerly it was concluded that, if the disease is caused by some " toxic substance ", it must be carried by the pregnant ewe (over a period of years) to exert a pathogenic effect only on the developing lamb. (Innes and Shearer, 1940; Bennetts, 1935). It was thus essential that this " toxic agent " could pass freely through the placenta in order to affect the brain of the foetus. However, it is not quite clear to us, why this toxin should have more affinity for the nervous tissue of the foetus than for that of its mother.

The possibility that the changes in the brain of the foetus need not necessarily be the immediate effect of a noxa passing from the maternal circulation through the placenta must be considered. It is conceivable that such a toxin—whether of exogenous or endogenous origin—may lead to vascular and/or circulatory changes in the placenta or it may affect the tissue respiration of the developing brain directly. A circulatory disturbance in the placenta caused by a noxa circulating in the maternal blood would be reflected in the foetal blood. The gaseous and metabolic interchange would be impeded which in turn would adversely affect the foetal tissues. Foremost amongst them would be the brain with its higher susceptibility to anoxaemia and the effects of accumulated catabolites. This would be manifested by a change in the pH of the involved areas. As a result, autolytic enzymes might be set free producing the focal areas of degeneration, the rarefaction and eventually the cystic changes which have been described. The process may be considered to be an aseptic autolysis. These changes can be easily differentiated from those of putrefaction which have different staining properties and may contain numerous putrefactive organisms.

The copper therapy may have the function of preventing the causal circulatory and metabolic disturbances responsible for the lesion. Its use is, therefore, not a symptomatic but a radical treatment.

Course.—The course of the disease may vary considerably. A number of lambs are born weak, are unable to rise, and remain lying in a prostrate position. They cannot suckle and eventually die of thirst and hunger. The lambs showing ataxia or those in which the symptoms develop later lag behind the flock and are apt to lose their mothers. The condition usually becomes progressively worse until the animal cannot rise any more and usually dies of inanition complicated with pneumonia. Some animals remain stunted, show signs of ataxia, stumble easily and may fall on their sides. Others apparently recover, are in the pink of condition, but when forced to move quickly, symptoms of ataxia and knuckling over of the hind fetlocks become apparent. Abnormalities in the wool, as previously mentioned, develop in sheep grazing on " affected " areas.

(II) A Biochemical Investigation on the Incidence of "Lamkruis" in Lambs in the Saldanha Bay, Vredenburg and St. Helena Bay Environs.

(Remarks by P. K. van der Merwe.)

Collection of Material.

Blood.—Blood samples (20-30 m.l.) were collected from individual animals in specially cleaned bottles containing copperfree Lithium citrate as anticoagulant.

Organs.—After the post-mortem the organs (liver, kidney and humerus) were carefully washed with copper-free distilled water and stored in copper-free, purified formalin solution.

Pasture samples.—Pasture samples (green) were collected and stored in glass jars and dried before destructive changes could set in.

Methods of Analysis.

Reagents.—The nitric and perchloric acids used in the wet ashing method were carefully re-distilled in an all-glass unit to render these acids copper free.

It was found that a gradual resorption of copper from the bottle takes place if these acids are stored for any length of time. This is especially the case with nitric acid. It is advisable to prepare only small supplies of these acids at a time.

The copper content of analytical reagent sulphuric acid shows wide variations and it is advisable to select (by trial and error) a batch with a low copper content.

The Determination of Copper.

A. *Blood.*—Three successive 5 ml. aliquots of the citrated blood are wet ashed according to the method of Eden and Green (1940), in a specially cleaned 8 inch by 1 inch tube.

The final clear acid residure is allowed to cool and two to three ml. water added to hydrolyze the stable nitrosyl-sulphuric acid (a point not stressed in the literature) and the contents of the tube again boiled to sulphuric-acid fumes.

The development of the yellow copper lake of diethyl-dithio carbonate and the final measurement of the extinction in the Pulrich Photometer is essentially the method outlined by Eden and Green (1940).

B. *Organs.*—The livers and kidneys were cut in thin slices with a stainless steel knife, dried to constant weight at 105° C. and powdered.

C. *Pasture Samples.*—The pasture samples were dried to constant weight and representative samples wet ashed.

It was found that the silica content of pasture samples exerts a marked influence on the final values arrived at for copper.

Apparently absorption of copper on the silica particles takes place. This is contrary to the findings of Piper (1938) who states that copper is precluded from absorption on silica if plant material is wet ashed with perchloric acid.

It was found in the present study that the addition of a few ml. of a staturated solution of copper-free sodium fluoride to the clear acid digest with a subsequent volatilization of hydrofluoric and hydrofluo-silinic acids results in a quantitative recovery of copper.

Anaemia in Ewes and Lambs.

The haemoglobin content of the blood of the ewes examined is definitely of a low order. Mean values of the order 6·4 to 7·76 were arrived at for the various groups.

From extensive work carried out by Bennetts and Beck (1942) it would appear that a haemoglobin content of less than 8·0 points to an anaemic condition.

A " normal " haemoglobin value for the blood of lambs is more difficult to arrive at, but from numerous determinations carried out both here and elsewhere it would appear that it is reasonable to accept haemoglobin values of less than an approximate 9·5 as a manifestation of anaemia.

No definite correlation exists between the haemoglobin content of the ewe's blood and the blood of the progeny.

The haemoglobin content of the ewe's blood is no indication of (*a*) the copper content of the ewe's blood, (*b*) the copper and iron status of the ewe's organs (kidneys and liver), (*c*) the haemoglobin content of the lamb's blood, (*d*) the copper content of the lamb's blood, (*e*) the development of an ataxic condition in the lamb.

The mean haemoglobin content of the blood of lambs examined is significantly higher than the corresponding mean value arrived at for the haemoglobin content of ewe's blood.

Unfortunately no blood haemoglobin values are available for the blood of both ewes and lambs from a " healthy " farm (Appendix I group H).

The Blood Copper.

The concentration of copper in the blood of sheep in health or apparent health shows a fair degree of variance. A normal value would reasonably fall in range 0·30 to 1·0 p.p.m. The lower value represents an average for healthy sheep on winter grazing in the Transvaal. The higher figure represents on an average the copper status of the blood of Karroo sheep pastured on vegetation with an average copper content of 14 parts per million. Probably the upper figure of this range is unduly high as it was shown at this Institute that some sheep pastured on Karroo vegetation may develop enzootic icterus, a pathologic condition characterized by a super-saturation of the liver, kidney and spleen with endogenous copper.

The copper status of the blood of ewes and lambs in the experimental group on the farm Witteklip (Coetzee) almost conforms to the lower " normal " copper level, whereas the blood copper value of the ewes in the control group (dosed) and not dropping ataxic lambs was within the " normal " range.

On the other hand, the limited number of cases examined from " affected " farms in other parts of the Vredenburg district definitely show that (*a*) a low copper status of the ewe's blood co-incides with a very low copper content of the lamb's blood (less than 0·1 p.p.m., this incidentally being the lowest concentration of copper that can be determined with any degree of accuracy of 10 ml. of blood); (b) the blood copper may fall to a very low level (less than 0·1 p.p.m.) without apparently interfering with normal haemopoiesis.

In two cases (Appendix I group G) lambs were found to exhibit definite symptoms of ataxia only when hard driven. These lambs were in the 6 to 8 weeks group.

This may be held to suggest that a gradual rehabilitation to a normal iron-copper metabolism may take place but that the intra-uterine injury to the central nervous system is permanent.

The Copper Status of the Organs.

The copper content of the livers of normal sheep falls within a very wide range and depends on numerous factors such as (a) the copper content of the pasture, (*b*) the ingestion of copper-containing medicines, (*c*) the actual mobilization of endogenous copper during the development of enzootic icterus, a condition which apparently enjoys a certain incidence in this country.

From numerous determinations carried out at this Institute it would appear that a copper range of 100 to 1,000 p.p.m. expressed on the absolute dry basis constitutes a reasonable normal range. It was shown at this Institute that in cases of enzootic icterus the copper content of livers of apparently healthy sheep. may reach the extreme value of seven thousand parts per million though the sheep definitely had no access to exogenous copper.

Without a single exception the copper value of the livers of the ewes and lambs from both healthy and affected farms in the Vredenburg district is at an exceptionally low order and falls comparatively speaking in a narrow range (2·2 to 24·9 p.p.m.).

The striking depletion of the copper stores of the liver and kidneys is accompanied in the majority of cases examined by a marked increase above the normal for the iron content of the liver and kidney.

This is identical to the state of affairs encountered by the Australian workers Underwood, Bennetts *et al.* and in one isolated case by du Toit and Schulz (1939) in this country.

In all cases examined and especially in the cases from farms other than the farm on which the experiment was conducted the incidence of ataxia is coupled with an exceedingly low copper content of both livers and kidneys. Again it should be pointed out that a low copper status of the liver and kidney of the ewe (in the cases examined) is not necessarily an indication that the development of an ataxic condition of the lamb is to be expected.

Five ewes from a " healthy " farm (see Appendix I group H) have a mean copper content of the liver of a lower order than ewes from " affected " farms, and yet the incidence of ataxia amongst this specific flock is unknown.

A significant difference between the ewes examined from the healthy farm and the ewes from affected farms is the " normal " iron status observed for the former group. The mean copper content of the livers of the lambs from the " healthy " farm is significantly higher than the mean value arrived at for lambs showing definite and marked signs of ataxia. Of special interest is the comparatively high " mean " copper content of the kidneys of these " healthy " lambs.

The Iron Status of the Organs.

The livers of " normal " sheep may vary greatly in their iron content and the definite establishment of a" normal " value is impracticable.

From available data it would appear, however, that a range of 500-800 p.p.m. could reasonably be held to represent a " normal " status of the iron deposits of the liver.

The metabolism of iron in the animal body is affected by a series of the most complex phenomena with the result that a definite reserve should be exercised in the discussion of a condition where the iron metabolism apparently deviates from the normal.

From the analytical data available it is observed that generally speaking the development of ataxia in the lamb follows on a depletion of the copper stores of the ewe's liver with the result that lambs are born with a very low copper reserve in the liver. The phenomenon is accompanied by a very marked increase in the iron content of the liver of both ewe and lamb, notable exceptions are by no means absent.

A study of the analytical data available points to the following development of the iron picture.

(*a*) An accumulation of iron in the liver of the lamb in intra-uterine life either due to a transportation or due to a destruction of the circulating blood of the ewe leading to a state of haemosiderosis; (*b*) a further accumulation of iron in the liver of the developing lamb either due to a deposition of immobilized iron or as a manifestation of haemosiderosis.

Of special interest is the iron-copper picture encountered in the organs of normal ewes and lambs from a healthy farm (Skuitjiesklip, Gersbach) (see Appendix I, group G).

As already pointed out the livers of these ewes have a very low copper content and a "normal" iron content. The lambs of these ewes show a liver and kidney copper value significantly higher than encountered in ataxic lambs. On the other hand the mean iron content of the livers of these apparently healthy lambs is of a very high order. One is left no option but to assume that immobilized iron is deposited in such livers and that factors are in operation which interfere with the normal iron metabolism of the ewe and the lamb. This assumption is verified histologically since very little iron is demonstrable in sections stained with Berliner Blue.

The Copper Content of the Pasture in Relation to the Development of Lamkruis.

The logical approach to an investigation of any pathologic condition with a possible deficiency of a minor element in the background naturally lies in the determining of the concentration of the specific element in question in the vegetation of the affected area.

A survey of the copper content of natural South African pastures reveals that a copper content of the absolute dry basis of 8-15 p.p.m. is obtained for pasture samples from healthy sheep country.

In a study of the copper metabolism of sheep as encountered in this country two extremes are represented. In the first instance factors are in operation which cause a marked depletion of the copper stores of the liver and kidney accompanied by a vast increase in the iron content of these organs, with the result that the condition termed lamkruis may set in. On the other hand, sheep pastured in the Karroo may develop the typical condition of enzootic icterus when removed to other parts of the country. It was shown at this Institute that Karroo sheep develop icterus when brought to Onderstepoort and fed on a ration of yellow mealies, crushed oats and lucerne hay which supplies a mere 2·6 milligrams of copper per day.

Enzootic icterus is characterized by a most phenomenal and almost fantastic accumulation of copper in the liver.

A survey of Appendix II reveals that the copper content of the pasture samples collected in the affected Vredenburg area is without a single exception of a very low order. It is well to bear in mind that these values are expressed on an absolute dry basis. The samples collected were in an early stage of growth.

If the dry matter feed consumption equation of Smuts and Marais i.e. D.M. $= 56W^{\frac{3}{4}}$ is applied it is evident that an extremely low daily copper intake is to be expected for both lambs and ewes. On the other hand, the copper value of a pasture sample collected from a healthy farm (Skuitjiesklip) is of the same approximate order as the individual and mixed samples collected from affected farms in the Vredenburg District. The iron content of all samples examined could reasonably be termed " normal ".

As sheep are known to exercise a curious selection in their grazing the pooled ruminal content of ewes and lambs were examined for their copper and iron contents. It is only natural that the copper content of ruminal material would be higher than the copper content of the pasture collected at random.

Of special interest is the exceptionally high iron content and acid insoluble residue of the ruminal content of both ewes and lambs from the farm on which the experiment was conducted. The high iron content of the ruminal content is either due to an accumulation of iron in the rumen brought about by some obscure factor or due to an extraneous contamination brought about by the high percentage of sand in the ruminal contents.

However, the same state of affairs prevails on another farm in the affected area (Sandfontein, Harris) where a marked accumulation of iron in the ruminal content exists not accompanied by a high acid insoluble residue.

If the concentration of copper in the ruminal contents of sheep from " affected " farms is compared with the copper content of the ruminal content of healthy Onderstepoort sheep, it is observed that a significant difference exists. However, the actual difference in the total quantity of copper present or available to the two groups of animals is not of such a magnitude that one is justified in the statement to the effect that the development of lamkruis in the developing lamb is due to a deficient daily intake of copper *per se,* especially, furthermore if the copper content of the pasture samples from " affected " and " healthy " farms is considered. The Australian workers and also du Toit and Schulz (1939), fostered the theory that ataxia in lambs usually develops where the soil is of a calcareous wind-blown nature, and that in soils of this type the copper compound is precluded from assimilation by plants. This " inhibition theory " of copper assimilation by plants from calcareous soils has been discredited by the work of Greenstein and van der Merwe (1940), who showed that a lime content of soil upwards to 60 per cent. has no effect on the assimilation of copper by the plant.

Du Toit's view that the copper compound in the soil is " carbonated " by the presence of high concentrations of lime in the soil, can scarcely be supported, as, if such a reaction should develop, the copper compound would be " bicarbonated " continuously passing in a reversible reaction from a stable to a labile phase, thus rendering the copper compound more readily available to the plant.

The copper content of pooled samples of topsoil from the farm on which the experiment was conducted showed an extremely low copper content (0·5 p.p.m.) but a decided increase in the copper content is observed when passing from the topsoil to the subsoil (2·2 p.p.m.). The copper content of pasture samples from this soil is not significantly lower than that of pasture samples obtained from soils with a copper content upwards to 8 p.p.m. (See Onderstepoort File 18/49 of 1/3/41.)

The Calcium and Phosphorus Status of the Long Bones of the Ewes in the Experimental Group.

Rossouw and Bekker (1930), and subsequently Malan and Thomas (1937), established a deficiency of phosphate as the causative factor in a condition which severely affects the Bontebok in the Bredasdorp Game Reserve and also sheep in the environs of the Game Reserve. It has been suggested by du Toit and Schulz (1939), that "lamkruis" may be a manifestation of a trace element deficiency, although these areas were deficient in phosphorus.

It was therefore decided to investigate the calcium oxide, phosphoric oxide ratio and ash content of the long bones of the ewes in the experimental groups (Appendix III).

Though it would appear in the light of present knowledge that states of bone resorption in the sheep are not reflected by examination of the humerus alone, yet one is probably justified in assuming that in the ewes examined bone calcification was sound and based on adequate daily supplies of calcium and phosphorus in the Vredenburg District. This was confirmed by microscopic and histologic examination of the skeleton, which apparently did not differ from the normal.

A comparison with the figure quoted by Underwood (1940) for healthy Australian sheep and by Stewart (1935) for English sheep, further confirms this statement.

III. Experimental Studies, Treatment and Control Measures.

Unfortunately the clinical diagnosis of "lamkruis" could not be confirmed in any of the animals mentioned in this group, by an anatomical, pathological or histological examination as no material was available for this purpose.

Experimental.

Since 1939 a series of field experiments were conducted in which the natural grazing in lamkruis areas was supplemented with trace elements. As cobalt and copper (Butt *et al.*, 1938) or copper alone (Bennetts, 1937) was by this time shown to be the primary deficiency in pastures where ataxia occurred in Australia, one or both of these elements were included in experimental mixtures. The following were the salt mixtures in solution given weekly as a drench. Lambs were given half the quantity allowed to mature sheep.

Table I.—Salt Mixtures used in Experiments.

Ref. No.	Minerals in Mixture.	Weekly Intake (gm.) (In 28 c.c. solution.
T.....	Copper Sulphate.....	0·012
	Cobalt Chloride.....	0·120
	Ferrous Chloride.....	0·032
	Zinc Sulphate.....	0·217
B.....	Copper Sulphate.....	0·187
	Cobalt Chloride.....	0·019
	Ferrous Chloride.....	0·373
	Manganese Sulphate.....	0·019
E.....	Copper Sulphate.....	0·187
	Cobalt Chloride.....	0·019
D.....	Copper Sulphate.....	0·187

Experiments with Lambs.

Experiment 1.—The first experiment conducted in 1939, was of a preliminary nature. On several farms in the afflicted areas healthy lambs of approximately one or two months old were selected and each given half a dose weekly of the T. mixture. Unfortunately some of the control lambs were also dosed as soon as the slightest signs of lamkruis became evident with the result that the control figures were not reliable. Although control lambs and many other lambs on these farms contracted lamkruis, none of the lambs dosed developed any of the symptoms.

Experiment 2.—In 1940 a series of controlled experiments were conducted on six different farms in the Saldanha Bay-Vredenburg Area. On each farm a number of lambs of from one to two months old were selected and divided at random into three groups, two groups being dosed weekly with the salt mixtures E and D and the third serving as control. On farm No. 10 mixture B was used as very favourable results were obtained with this mixture the previous season. The experiment lasted for approximately three months.

TABLE 2.—COPPER AND COBALT SUPPLEMENTS FOR PREVENTING LAMKRUIS IN LAMBS.

Farm Ref. No.	Group I. Mixture E(Cu Co)		Group II. Mixture D(Cu).		Group III (Control) Water Methyl Orange.	
	No. Dosed.	No. Lamkruis.	No. Dosed.	No. Lamkruis.	No. Dosed.	No. Lamkruis.
1	15	0	15	0	15	1
2	10	0	10	0	10	0
3	10	0	10	0	10	0
4	10	2	10	0	10	4
8	10	0	10	0	10	4
10	10	0	—	—	10	6
TOTAL	65	2	55	0	65	15
PER CENT.	—	3·1	—	0	—	23·1

Only two out of 120 lambs (1·7 per cent.) receiving copper or cobalt and copper supplements developed lamkruis, whereas 15 out of 65 (23·1 per cent.) receiving no supplements developed the symptoms of lamkruis. One of the copper-cobalt group that developed lamkruis was probably on the verge of developing the symptoms when selected, as the first indications were noticeable only four days after the commencement of the experiment. The other one developed it a month later. We cannot account for these two cases as they were the only ones that occurred in all our experiments where a copper salt was one of the supplements given to lambs or pregnant ewes.

It would appear from the above table that a copper containing supplement prevented the incidence of lamkruis when given to lambs as a weekly drench with an intake of 93·5 mgm. of copper sulphate per lamb per week. As the copper salt alone gave as good results as the copper-cobalt mixture, one may deduce that lamkruis may be associated with a copper deficiency in the natural pasturage.

It is of historical interest that in the coastal areas of Albertinia the farmers stumbled on copper sulphate as a remedy against lamkruis at least thirty years ago. It is related by the older farmers that copper sulphate was successfully used as a remedy against lameness in young ostriches (probably due to worm infestation) and that this induced them to try it as a remedy against lamkruis in lambs. A table spoon full of copper sulphate is dissolved in a wine bottle of water (plus minus 750 c.c.) and of this solution the following quantities are given as monthly doses:—

(i) One tablespoon full to sheep of 9 months and older.

(ii) Half a tablespoon full to sheep of 3-9 months old.

(iii) A teaspoon full to lambs of 1-3 months old.

This monthly dose greatly decreased the occurrence of lamkruis.

The Influence on Live Weights of Lambs.

The lambs were weighed at the commencement and end of the experiment which lasted three months excepting on farms 1 and 2 where the duration was four months. Results are given in Table 3.

TABLE 3.

Live Weights of Lambs in lb.

Farm Reference No.	GROUP I (Cu+Co).				GROUP II (Cu).				GROUP III (Control).			
	No. of Lambs.	Average Weights.			No. of Lambs.	Average Weights.			No. of Lambs.	Average Weights.		
		Initial.	Final.	Increase. Per cent.		Initial.	Final.	Increase. Per cent.		Initial.	Final.	Increase. Per cent.
1.....	14	34·4	47·9	39·2	15	32·9	49·7	51·1	15	28·5	45·6	60·0
2.....	9	18·9	48·8	158·1	8	17·4	50·9	192·5	9	22·1	56·4	155·2
4.....	9	16·0	34·5	115·6	10	16·4	35·8	118·3	8	17·4	36·7	110·9
8.....	8	24·7	44·6	80·6	9	22·5	38·1	69·3	7	21·7	33·7	55·3
10.....	10	15·3	49·6	212·0	—	—	—	—	10	17·3	44·2	155·5

When applying Fisher's test it was found that only on two farms, viz. 8 and 10, were the differences significant and both these were in the Cu + Co versus the control groups. Both these farms are known for their high incidence of lamkruis. This might have been taken as an indication that the cobalt had some beneficial influence if it had not been that the lamkruis lambs of the control group were definitely at a disadvantage for moving freely and grazing normally.

Experiments with Pregnant Ewes.

Experiment 1.—*Dosing Ewes with Salts of the Trace Elements.*—The object of this experiment was to supplement the coastal grazing of pregnant ewes with possible deficient elements instead of moving them to healthy pastures. On seven different farms spread over the Saldanha-Bay-Vredenburg area ewes were selected, tagged and divided at random into two groups, the one group to serve as control and the other to be dosed at weekly intervals with mixture B. They all ran together in the main flocks. Dosing was commenced on 23/12/49 when the rams were also put to the ewes. On four of the farms dosing was continued to the end of May, on two to the end of June and on one to the end of August. The results are given in Table 4.

TABLE 4.

Dosing of Ewes to Prevent Lamkruis in Lambs.

Farms Reference No.	No. of Ewes in Exp.	No. of Ewes Lambed.	No. of Lambs Dropped.	No. of Deaths.	No. of Deaths due to Lamkruis.	Alive with Symptoms of Lamkruis.	Total Lamkruis.
			Group I (Controls).				
1.....	15	15	15	9	9	0	9
5.....	15	11	11	5	3	0	3
6.....	15	9	9	2	1	0	1
7.....	15	11	12	9	9	1	10
8.....	15	12	12	8	7	0	7
9.....	13	8	8	0	0	3	3
10.....	15	10	10	7	2	2	4
TOTAL.....	103	76	77	40	31	6	37
PER CENT.....	—	73·8	74·8	42·0	40·3	7·8	48·1
			Group II (Dosed).				
1.....	15	14	14	0	0	0	0
5.....	15	11	11	4	0	0	0
6.....	15	10	10	0	0	0	0
7.....	15	12	16	1	0	0	0
8.....	45	41	41	1	0	0	0
9.....	15	13	13	3	0	0	0
10.....	15	14	14	1	0	0	0
TOTAL.....	135	115	119	10	0	0	0
PER CENT.....	—	85·2	88·1	8·4	0	0	0

The outstanding feature of this experiment is that not a single lamb dropped by the dosed ewes contracted lamkruis, whereas 48 per cent. of the lambs born from the control ewes developed the symptoms. From this it is clear that a weekly drench of the B. mixture given to ewes kept on deficient pastures will inhibit the incidence of lamkruis in lambs dropped from them. Another feature is the higher lambing percentage of the dosed ewes showing an increase of 11·5 per cent. over the controls. Also the high mortality of lambs in the control group is very striking. This can be accounted for by the high mortality amongst the lamkruis lambs of which 77·5 per cent. eventually died.

Experiment 2.—*Giving Copper Sulphate to Ewes with a Feed* (1940-41).—In this experiment only copper sulphate was allowed to ewes, not as a drench but absorbed in crushed oats. The object was to ascertain whether copper alone would have the same effect as the B mixture in preventing the occurrence of lamkruis in their lambs and secondly to try an easier, yet equally effective means of supplementing the trace element deficiency of the pastures. Crushed oats was used for this purpose as it proved to be a good absorber of the copper sulphate solution and the sheep take to it readily.

On each of the farms Nos. 5 and 8, 220 ewes were selected and divided into three groups. Group I consisted of 150 ewes and were allowed a ration once a week consisting of 15 lb. of crushed oats treated with 28 grm. of copper sulphate in solution. This would allow an intake of ·187 grm. of copper sulphate per week per sheep. Group II consisted of 50 ewes which were dosed weekly with copper sulphate solution to give a weekly intake of ·187 grm. of copper sulphate per sheep. Group III consisted of 20 ewes which were to serve as control. The ewes were all run together in the same flock. Rams were put in with the ewes in December, supplementing commenced in February and continued for four months.

In the case of farm No. 5, to the surprise of the owner himself none of the lambs of the control group developed lamkruis. It will therefore suffice to state that also none of the 200 ewes allowed the copper sulphate dropped lambs that developed the malady. It was however noticed that the percentage of lambs was greater in the supplemented than in the unsupplemented group.

The results obtained on farm No. 8 are given in Table 5.

TABLE 5.

Influence of Copper Sulphate on the Incidence of Lamkruis.

Group.	No. of Ewes.	No. of Ewes Lambed.	No. of Pregnant Ewes Died.	Total in Lamb.	Per Cent. in Lamb.	No. of Lamkruis. Lambs.	Per Cent. of Lambs.
1. (Cu Oats)...	150	83	30	113	75	0	0
2. (Cu).....	50	43	4	47	94	0	0
3. (Control)...	20	8	4	12	60	7	87·5

The main features of the results obtained on the one farm were:—

(i) The high incidence of lamkruis in lambs dropped by the unsupplemented ewes. Of the eight lambs dropped alive seven contracted lamkruis.

(ii) The complete prevention of lamkruis in lambs by supplementing the mothers when pregnant with a copper salt only.
(iii) The high effectiveness of adding the supplement to the feed as compared with the method of giving it as a drench.
(iv) The higher percentage of the copper supplemented ewes that came in lambs.

We may conclude from this experiment that ·187 grams of copper sulphate per ewe given weekly with the feed during the gestation period will prevent lamkruis occurring in their lambs. If only small quantities of feed are given as in this experiment, special care must be taken that all the ewes get their due share. Oats was used as a meduim in this experiment at it was available on the farms, the sheep took to it readily and it was grown in the copper-deficient areas. In general practice any feed can be used and it may prove practicable to incorporate the deficient elements in feed pellets that can be broadcasted to sheep.

Influence on Live Weights of Ewes.

The live weights of the ewes used in Exp. 1 were taken but no reliable conclusions can be drawn from these on account of the high percentage of lambs that died in the control group thus relieving the mothers from the extra drain on their bodies caused by suckling lambs.

Influence on Haemoglobin Content of Blood.

During August 1940 haemoglobin determinations were made on the blood of ewes used in Experiment 1. The determinations were made with a Sicca haemometer. The Hb readings correspond with the Haldane standard. The results are given in Table 6.

When comparing the whole of the dosed group with the control group it appears that there is a significant difference in favour of the dosed group. However, when the results of the individual farms are compared we find that only on one farm (No. 7) did the dosed group show a significantly higher haemoglobin value than the control group.

In the course of our various experiments 189 haemoglobin determinations were made on the blood of sheep in the coastal regions and 56 in the interior. There was found to be a general trend for higher values on the inland farms than on the coast, the average being 79·7 per cent. for the coastal and 97·3 per cent. for the more inland farms. Of the voastal regions Vredenburg-Saldanha Bay area gave on the average the lowest value. An outstanding feature was the very wide variations in Hb values amongst sheep.

Control Measures.

Any control measure should aim at preventing and not at curing the disease.

If ewes are not given a regular change of pasture outside these coastal areas, lamkruis may be controlled in their lambs by any of the following measures:-

1. From the time the ewes are put to the ram they must be given a dose of copper sulphate at least once weekly at the rate of 0·187 grm. per ewe per week. One ounce of copper sulphate to be dissolved in one gallon of rain water and this solution given at the rate of one ounce per sheep per week. Enamel, glass or earthern ware receptacles must be used.
2. Where sheep take a lick the copper salt may be added to the lick. Add 8 ounces of copper sulphate to 100 lb of lick.

TABLE 6.—*Haemoglobin Readings of Blood of Experimental Ewes.*

Farm Reference No.	Dosed Group.			Control Group.			Diff. of Means.	Value of t.	Sign Values of t.
	No. of Ewes.	Variation in Hb.	Average Hb. Per Cent.	No. of Ewes.	Variation in Hb.	Average Hb. Per Cent.			
1	9	57–80	70·6	9	61–72	64·8	5·8	1·947	2·120
5	5	56–86	71·6	5	58–76	69·4	2·2	0·369	2·306
6	4	68–76	72·0	5	58–88	69·4	2·6	0·428	2·262
7	15	65–88	78·6	13	50–86	70·8	7·8	2·304	2·056(s)
10	10	56–98	77·7	12	52–100	69·2	8·5	1·356	2·086
TOTAL	43	56–98	75·3	44	50–100	68·8	6·5	2·755	1·960(s)

3. The copper sulphate may be given with a feed. Add one ounce of copper sulphate to the week's ration of 150 ewes. The copper sulphate should be dissolved in 1 gallon of rain water and this thoroughly mixed with feed. The necessary precaution must be taken that all the ewes get their due share of the feed. Feeding should commence when the ewes are put to the ram and should continue at least until lambing time. Crushed oats have proved to be a good absorbent of the solution and are readily taken by sheep. Copper sulphate may also be incorporated in feed pellets or blocks for feeding sheep in lamkruis areas.
4. To lambs of one month and older whose dams had no copper supplements or change to healthy pastures give half an ounce weekly of a solution of one ounce copper sulphate in a gallon of rain water.
5. In Australia the topdressing of pastures at the rate of 10 to 20 lb. of copper sulphate per acre has given good results. In the grain area of our coastal belt the chief grazing is obtained from the grain lands Fertilizing these lands with a copper salt for increased yields may also prove to be a practical means for controlling lamkruis in these areas. Experiments in progress are showing promising results.

Summary and Conclusion.

It cannot be claimed that the observations recorded have led to specific information as to the cause of the disease known as " lamkruis ", yet valuable information has been obtained which makes it clear that the factors originally suspected, i.e phosphorus and copper deficiency, can now be disregarded as the primary aetiologic factors.

An ataxia of lambs called " lamkruis " or " litsiekte " was found to occur on the south and west coast of South Africa, mostly on the calcareous soils of recent origin but also on soils of partly granitic origin. Clinically it is a non-febrile disease characterized by a swaying gait in the hindquarters. When the lambs are driven they stumble easily and fall on to their sides. The striking pathologic feature is destruction of the myelin in the nervous system, and, in extreme cases, symmetrical areas of softening or cavity formation occur in both cerebral hemispheres. The white brain substance is principally affected. Cavity formation is extemely rare in the spinal cord.

Lamkruis is probably identical with other demyelinating diseases affecting lambs in various parts of the world, for instance, enzootic ataxia or ataxia of young lambs in Australia and New Zealand, " swayback " or " singback ", or " warfa " in England and Scotland, and " renguera " in Peru, Patagonia and the Argentine.

" Lamkruis " as we know it in this country only develops in the progeny of ewes subjected to a pasture of a " low " copper content. Without a single exception the liver copper value of both ewes and their lambs was of a low order. There is evidence, however, that a low copper content of the liver is not pathognomonic for lamkruis.

Presumably, therefore, the ataxia is not necessarily caused primarily by a copper deficiency.

The ataxia is, therefore, probably not due to a copper deficiency alone. In this respect it differs from enzootic ataxia or ataxia of young lambs and is similar to swayback and renguera. It is assumed that copper may only be a link of a chain of *contri*butory causes. The process of demyelination cannot be ascribed to a single factor such as a copper deficiency.

It has been shown that, although the common lesion-demyelination is an anatomical entity, its aetiology need not necessarily be identical in each case. The view is expressed that in the case of "lamkruis" the lesions must be correlated with a circulatory disturbance and/or a possible defective tissue anabolism brought about by a deficiency of circulating copper. The bilateral symmetry of the lesions suggests a systemic involvement.

The beneficial effect of administering copper salts to pregnant ewes in reducing or preventing the appearance of "lamkruis" in their progeny has been demonstrated. In this respect our findings are in close agreement with those of the other demyelinating diseases of lambs. It cannot be claimed, however, that the administration of copper salt has a curative effect on diseased lambs.

The administration of copper salts to affected lambs may seem to have a curative effect in some cases. It should be remebered however that a number of animals may recover without any treatment at all. Apparent or total recovery, probably depends on the extent and degree of the lesion and the affected structure.

Presumably in "lamkruis" the demyelination is due to a patho-physiologic process and the beneficial effects of copper may be ascribed to its physiologic or therapeutic properties rather than to its direct association with myelination.

The ataxia seen in "lamkruis" is presumably not associated with the lesions in the cerebral hemispheres, since there was no relationship between the severity of the clinical symptoms and the extent of the lesions. The possibility that the ataxia is associated with alterations in the cerebellum or brain-stem or both, must be considered.

The high concentration of iron and the low copper level in the livers of adult sheep and lambs on "affected" properties indicate a disturbance in the iron metabolism and may possibly be due to the absence from the food supply of some factor (cobalt) necessary for its utilization as is the case in enzootic marasmus. Presumably most of this iron is immobilized and stored in the organs, since only a very small amount is demonstrable in sections stained with Berliner Blue and this does not occur principally in the form of haemosiderin.

The haemoglobin values for both ewes and lambs may reasonably be considered to be of a low order. However, the magnitude of the values obtained is not such that one is justified in stating that haemoglobin synthesis and haemopoiesis have seriously been affected, since a very low blood copper level (less than 0·1 p.p.m.) apparently does not interfere with normal haemopoiesis.

Evidence has been produced suggesting that a gradual rehabilitation to a normal iron-copper metabolism may take place but that the intra-uterine injury to the central nervous system may be permanent.

It seems that the biochemical processes concerned in the copper and iron metabolism of the body may proceed normally, in spite of a marked depletion of the copper stores of the ewes and the developing lamb, and the condition may further be complicated by a significant deviation of the iron stores of the body from the normal.

Based on the present evidence we wish to emphasise a post-natal as well as a pre-natal onset for "lamkruis" and related diseases. Possibly all cases developing within three months after birth may be looked upon as "delayed" pre-natal cases, whereas those occurring later are most likely post-natal. Although the end results may be identical, the pathogenesis in the various forms may differ in several respects.

A reduced phosphorus content was demonstrated in the soil, the vegetation, the blood and tissues of stock grazing on the " Strandveld " (Bredasdorp, Riversdale and Swellendam areas) and this was reflected in softness and fragility of the bones of the animals concerned, whereas no evidence of an apparent phosphorus deficiency was obtained in the vicinity of Saldanha Bay and Vredenburg.

Phosphorus deficiency is probably a contributory factor of the disease called " heupsiekte " in cattle and that which was mistakenly termed " lamkruis " in older sheep by former investigators. The disease described by us has nothing in common with the previously mentioned condition.

In some of these coastal areas several diseases, such as " duinesiekte " of sheep and young cattle, paratyphoid of calves, and " broken wind " in draught animals (called " ruksiekte " or " benoudebors ") or " bighead " (osteofibrosis) in horses, may be very prevalent. The possibility of greater susceptibility of animals to diseases under conditions prevailing in these coastal regions is a problem that requires further investigation.

Other diseases, for instance " slapsiekte " of lambs and donkeys, affections of lambs and goats due to *Coenurus cerebralis,* and " Malkop " occurring more inland and characterized by nervous symptoms, have been described. In addition some demyelinating diseases affecting man and presumably not associated with a copper deficiency have been mentioned. Evidence has been thereby produced indicating that diseases with similar clinical symptoms and morbid changes need not necessarily have the same aetiology. However, there may be some common factor responsible for their similarity.

" Lamkruis " is not related to imperfect osteogenesis nor to a degeneration of the musculature as that seen in " white muscle " disease. The alterations in the central nervous system are not those of aplasia of the white substance of the brain nor of an inflammatory nature, *but must be ascribed to an encephalomyelopathy or a diffuse leucoencephalopathy without sclerosis.* The process in cavity formation appears to be that of autolysis occurring *intra vitam.* It is characterized by a scarcity of fat and " gitter cells ". In this respect " lamkruis " differs significantly from Schilder's Disease, but is in close agreement with diffuse leucoencephalopathy of man (Josephy and Lichtenstein, 1943). Post mortem changes can be eliminated since the specimens were placed into formalin within a few minutes after slaughtering of the animals. Deficiencies of copper, phosphorus and vitamins may be excluded as primary causes, but they probably act as contributory factors. Apparently poisonous plants and fungi do not play a role in the aetiology of this disease.

As the disease may occur intra-uterine it is essential that the placental circulation (maternal and foetal) and the chemical changes occurring in the foetal brain should receive more attention than in the past. Progress in elucidating the pathogenesis of " lamkruis " and other related diseases may be expected, if the significance of these two factors will be fully appreciated.

It is well-known that several demyelinating diseases occur in man and that demyelination can be produced experimentally by a number of variable factors and not necessarily by a copper deficiency.

Our cases, as well as those mentioned in the literature, point to the necessity for careful neurologic study in all cases of " lamkruis " and similar conditions. The distribution and character of cerebral lesions in " lamkruis " are indicative of circulatory disturbances and the resultant alterations in the affected localities. *More attention should be given to less pronounced changes, especially in the cerebellum, brain-stem and other organs, for instance the adrenal.*

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LITERATURE REFERENCES.

ASKEW, H. O. and RIGG, T. (1932). *N.Z.J. Dept. Sci. and Ind. Res.,* Bull. No. 32.

AYCHET, M. (1938). Une des enteritis toxiques des angeaux (La paraplegic enzootique). *Ecole Nat. Veterin. Alfort, Paris*: *Diss* 1938.

BEKKER, J. G. and ROSSOUW, S. D. (1930). Note on some Conditions in Sheep in the Strandveld of the Bredasdorp District. *16th Rept. Dir. Vet. Serv. & Anim. Indust. Union of South Africa.,* p. 293.

BENNETTS, H. W. (1932). Enzootic Ataxia of Lambs in Western Australia. *Aust. Vet. J.,* Vol. 8, pp. 137 and 183.

BENNETTS, H. W. (1935). The Prophylaxis of Enzootic Ataxia of Lambs in Western Australia. *J. Coun. Sci. Ind. Res.,* Vol. 8, p.61.

BENNETTS, H. W. and CHAPMAN, F. E. (1937a). Copper Deficiency in Sheep in Western Australia; a Preliminary Account of the Etiology of Enzootic Ataxia of Lambs and an Anaemia in Ewes. *Austr. Vet. J.,* Vol. 13, p. 138.

BENNETTS, H. W. (1937b). Copper Deficiency—The Cause of Enzootic Ataxia (" Ricketts ") of Lambs. *Ibid.,* Vol. 14, p. 247.

BENNETTS, H. W. (1940). Coast Disease in Western Australia *J. Agr. West, Aust.,* Vol. 17. p. 41.

BENNETTS, H. W. (1941). " Falling Disease " of Cattle in South West. *J. Agr. West. Aust.,* Vol. 18, p. 133, 1941.

BENNETTS, H. W. and BECK, A. B. (1942a). Enzootic Ataxia and Copper Deficiency of Sheep in Western Australia. *Commonwealth Austral. Counc. Sci. Indus. Res. Bull.* No. 147

BENNETTS, H. W., HARLEY, R. and EVANS, S. T. (1942*b*). Copper Deficiency of Cattle and the Fatal Termination " Falling Disease ". *Aust. Vet. J.,* Vol. 18, p. 50.

BENNETTS, H. W. (1942*c*). " Stringy " Wool and Copper Deficiency in Western Australia. *J. Agr. West. Aust.,* Vol. 19, p. 7.

BENNETTS, H. W., BECK, A. B., HARLEY, R. and EVANS, S. T. (1941*a*). " Falling Disease " of Cattle in the South West of Western Australia. *Aust. Vet. J.,* Vol. 17, p. 85.

BULL, L. B., MARSTON, H. B., MURNANE, D. and LINES, E.W.L. (1938). III. Ataxia in Young Lambs. *Commonwealth Austral. Counc. Sci. Indust. Res.,* Bull. No. 113, p. 23.

CLARK, R. (1938). A Note on Paralysis Caused Apparently by Rhipicephalus evertsi. *J.S.A.V.M.A.,* Vol. 9, p. 143.

CORNER, H. H. (1939). Pine Diseases in Sheep. *Agric. Progress,* Vol. 16, p. 181.

CUNNINGHAM, I. J. (1944). Copper Deficiency in Cattle and Sheep. Occurrence and Control in New Zealand. *N.Z.J. Agric.,* Vol. 69, p. 599.

CUNNINGHAM, I. J. (1946). Copper Deficiency in Cattle and Sheep on Peat Lands. *N.Z.J. Sci. Tech.*, Vol. 27, p. 381.

DUNLOP, G. and WELLS, H. E. (1938). "Warfa" ("Swayback") in Lambs in North Derbyshire and its prevention by adding Copper Supplements to the Diet of the Ewes during Gestation. *Vet. Rec.*, Vol. 50, p. 1175.

DUNLOP, G., INNES, J. R. M., SHEARER, G. D. and WELLS, H. E. (1939). "Swayback" Studies in North Derbyshire. I. The feeding of Copper to Pregnant Ewes in the Control of Swayback. *J. Comp. Path and Therap.*, Vol. 52, p. 259.

DUNLOP, G. (1945). Mineral Deficiency Conditions in Sheep on Scottish Hill Grazings. *Proc. Nutr. Soc.*, Vol. 4, p. 69.

DUNNING, F. J. (1933). Swing Back in Lambs. *Vet. J.*, Vol. 89, p. 74.

DU TOIT, B. and SCHULZ, K. C. A. (1939). Unpublished Reports on paretic conditions in Stock in the Willowmore District and Strandveld.

EDEN, A., HUNTER, A. H., and GREEN, H. H. (1945). Contributions to the Study of Swayback in Lambs. II. Blood Copper Investigation. *J. Comp. Path. and Therap.*, Vol. 55, p. 29.

FILMER, J. F. (1933). Enzootic Marasmus of Cattle and Sheep. Preliminary Report having Special Reference to Iron and Liver Therapy. *Aust. Vet. J.*, Vol. 9, p. 163.

FISHER, R. A. Statistical Methods for Research Workers.

HUNTER, A. H., EDEN, A. and GREEN, H. H. (1945). Contributions to the Study of Swayback in Lambs. 1. Field Experiments. *J. Comp. Path. and Therap.*, Vol. 55, p. 19.

Information Circular, Straight Steely Wool and Incipient Cu and Co Deficiency in South Australia. *J. Dept. Agric. S. Aust.*

INNES, J. R. M. (1939), Swayback: A Demyelinating Disease of Lambs with Affinities to Schilder's Encephalitis and its prevention by Copper. *J. Neurol. and Psychiat. N.S.* Vol. 2, p. 323.

INNES, J. R. M. and SHEARER, G. D. (1940). I. "Swayback", a demyelinating Disease of Lambs with Affinities to Schilder's Encephalitis in Man. *J. Comp. Path. and Therap.*, Vol. 53, p. 1.

JONES, F. S. and ARNOLD, J. F. (1947). Staggers in Sheep in Patagonia. *J. Exp. Med.*, Vol. 26, p. 805.

JOSEPHY, H. and LICHTENSTEIN, B. W. (1943). Diffuse Leukoencephalopathy without Sclerosis: Clinico-pathologic Study of a New Form with Comment on various types of so-called diffuse Sclerosis and Schilder's disease. *J. Neurol. and Psychiat.*, Vol. 50, p. 575.

KELLERMAN, J. H. and SCHULZ, K. C. A. Unpublished data.

LANDBOUWEEKBLAD-REDAKSIE (1946). Lamkruis by Skape. Voorbehoedmiddel teen Siekte gevind. *Landbouweekblad*, Bd. 23 No. 1423, p. 25.

LEE, H. J. & Moule, G. R. (1947). Copper Deficiency Affecting Sheep in Queensland. *Aust. Vet. J.*, Vol. 23, p. 303.

MATHEWS, F. P. (1942). Fern Poisoning in Sheep, Goats and Cattle. The so-called "Jimmies" of the Trans-Pecos. *Bull.* 611. *Texas Agric. Exp, Stn.*

McDIARMID, A. (1948). Studies on Enzootic Staphylococcal Infection in Lambs associated with Tick-bite. IV Pathogenicity of the Causal Organism in the Lamb. *Vet. Rec.*, Vol. 60, p. 1.

McDONALD, I. W. (1942). Enzootic Ataxia of Lambs in South Australia. *Aust. Vet. J.*, Vol. 18, p. 165.

METZGER, H. J. and HAGAN, W. A. (1927). The So-called Stiff Lambs. *The Corn. Vet.*, Vol. 18, p. 35.

PIERCY, S. E. (1934). "Cripples" in Lambs, I. *Vet. J.*, Vol. 90, p. 53.

STEYN, D. G. (1931). Investigations into the cause of Alopecia (Kaalsiekte) in Kids and Lambs, 17*th Rep. Dir. Vet. Serv. & Anim. Indust. Union of South Africa,* p. 729.

STEWART, W. L. (1932). Swingback (Ataxia) in Lambs. *Vet. J.,* Vol. 88, p. 133.

STEWART, W. LYLE (1933). " Cripples " in Lambs. *Vet. J.,* Vol. 89, p. 63.

SWART, J. C. and VAN RENSBURG, P. J. To be published in this Journal.

TABUSSO, M. E. (1941). *Publ. Inst. nac. Biol. Anim.,* Vol. 1, No. 1 ref. Innes, 1943.

THEILER, G. and SCHULZ, K. (1948). Unpublished Report.

THOMAS, A. D. and MALAN, A. (1937). Unpublished Report.

TRUTER, G. J. and SCHULZ, K. C. A. Unpublished Data.

UNDERWOOD, E. J. (1934). Enzootic Marasmus. *Aust. Vet. J.,* Vol. 10, p. 87.

UNDERWOOD, E. J. and BECK, A. B. (1941). Enzootic Marasmus. The Relation of Copper to Incidence and Treatment. *Aust. Vet. J.,* Vol. 17, p. 115.

VAWTER, L. R. and RECORDS, E. (1939). Observations on the Stiff Lamb Problem with Special Reference to White Muscle Disease. *J.A.V.M.A.,* Vol. 94, p. 489.

WILLIAMS, J. G., STEYN, D. G. and GROENEWALD, J. W. (1938). An Investigation into the Nature and Cause of a Disease in Newborn Merino Lambs affecting the Thyroids and Nervous System. *J.S.A.V.M.A.,* Vol. 9, p 182.

WILLMAN, J. P., ASDELL, S. A. and OLAFSON, P. (1934). An Investigation of the Cause of the Stiff-Lamb Disease. *Bul.* 603, *Corn. Univ. Agric. Exp. Stn. Ithaca, New York.*

WILLMAN, J. P., LOOSLI, J. K., ASDELL, S. A., MORRISSON, F. B. and OLAFSON, P. (1945). Prevention and Cure of Muscular Stiffness (" Stiff-Lamb " Disease) in Lambs. *J. Anim. Sci.,* Vol. 4, p. 128.

WOLF, A. and PAPPENHEIMER, A. M. (1931). The Histopathology of Nutritional Encephalomalacia of Chicks. *J. Exp. Med., Vol.* 54, p. 399.

APPENDIX II.—*Analysis of Pasture and Ruminal Contents.*

Locality.	Sample.	Pasture.		Ewes.	Ruminal Contents.			Lambs.	Ruminal Contents.		
		Cu.	Fe.		Cu.	Fe.	HCl. I.R, Per Cent.		Cu.	Fe.	HCl. I.R. Per Cent.
Farm	Mixed Samples	3·58	180·4	5	5·87	1,011	13·8	8	5·69	1,835	35·59
Witteklip	Vaalbos	3·92	159·8	5	5·79	1,020	13·0	8	6·20	1,762	38·86
(Coetzee)	Stinkruit	2·74	194·6	5	6·14	1,034	15·91	8	6·02	1,794	33·74
(Affected Area)	Ramnas	2·66	204·5	—	—	—	—	—	—	—	—
	Mean	3·28	184·8	Mean.	5·93	1,022	14·24	Mean.	5·97	1,797	36·06
Sandfontein (Harris)	Mixed Pasture	3·31	237·4	—	—	—	—	3	7·67	1,128	4·46
Swartrug (Pienaar)	Mixed Pasture	3·98	184·4	—	—	—	—	—	—	—	—
Skuitjiesklip (Gersbach)	Mixed Pasture	4·57	206·3	—	—	—	—	—	—	—	—
Kliprug (Pienaar)	Mixed Pasture	3·60	126·6	—	—	—	—	—	—	—	—
Witteklip (Loubser)	Mixed Pasture	2·61	174·6	—	—	—	—	—	—	—	—
Onderstepoort (Healthy)	Yellow Maize	2·08	—	1	9·84	218·1	1·94	—	—	—	—
	Crushed Oats	3·09	—	1	10·67	237·4	2·34	—	—	—	—
	Lucerne Hay	7·44	—	1	10·14	225·3	1·86	—	—	—	—
	—	—	—	Mean.	10·22	226·9	2·05	—	—	—	—
Beaufort West	(14 Samples Karroo Vegetation)	12·1	—	—	—	—	—	—	—	—	—

APPENDIX III.—*Analysis of Humerus of Ewes in Experimental Group.*

Group.	No. of Sheep.	Total Ash.	CaO Per Cent.	P_2O_5 Per Cent.	CaO : P_2O_5
A	4	65·6	35·8	27·2	1·32 : 1·0
B	2	64·9	33·9	26·8	1·27 : 1·0
C	3	64·3	34·5	27·0	1·24 : 1·0
D	4	65·1	34·9	26·4	1·32 : 1·0
E	4	63·8	35·1	25·9	1·35 : 1·0
F	2	65·4	34·5	26·3	1·31 : 1·0
G	—	—	—	—	—
H	5	64·8	34·7	26·0	1·33 : 1·0

APPENDIX I.—*Table of*

Ewes,

Group.	Blood.		Liver.		Kidney.	
	Hb.	Cu.	Cu.	Fe.	Cu.	Fe.
A.	8·26	0·38	13·68	945·2	5·21	120·1
	9·02	0·26	14·93	1,582	8·34	240·2
	5·31	0·24	11·14	2,212·4	4·91	870·6
	5·31	0·30	12·28	1,713	5·78	90·7
Mean	6·97	0·295	13·0	1,613·1	6·06	330·4
B.	8·90	0·32	—	—	—	—
	6·0	0·30	—	—	—	—
	6·64	0·36	13·80	3,267·4	3·8	216
	7·89	0·28	—	—	—	—
	9·16	0·34	—	—	—	—
	6·31	0·38	9·02	965·7	—	—
Mean	7·48	0·33	11·41	2,116·5	3·8	216
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	No material from ewes.		—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
C.	—	—	7·85	584·1	—	—
	8·37	0·24	10·76	2,611·4	—	—
	8·26	0·30	11·26	2,119·0	—	—
Mean	8·31	0·27	9·96	1,771·5	—	—
	—	—	—	—	—	—
	—	No material from ewes.		—	—	—
	—	—	—	—	—	—
D.	7·89	0·22	9·51	1,445·7	—	—
	7·43	0·24	15·84	1,247	—	—
	6·47	0·36	22·58	954·3	—	—
	5·49	0·44	11·05	1,690	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
Mean	6·82	0·36	14·77	1,334·2	—	—
E.	8·54	0·24	7·16	2,481	5·84	283
	5·61	0·38	10·27	1,844	9·24	441
	6·16	0·42	24·91	1,910	14·82	534
	8·48	0·36	17·82	844	13·74	84·6
	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
Mean	7·19	0·35	15·04	1,519	10·91	335·6
F.	5·49	0·30	—	—	—	—
	7·52	0·36	8·09	1,032	6·82	96
	7·39	0·22	16·41	392·6	11·42	220
	—	—	—	—	—	—
Mean	6·80	0·29	12·25	606·1	9·12	158
	—	—	—	—	—	—
	—	—	No material from ewes.		—	—
	—	—	—	—	—	—
H.	—	—	11·08	629·4	9·34	84·9
	—	—	8·21	936·9	8·93	118·6
	—	—	9·0	459·5	8·66	92·8
	—	—	12·25	428·5	10·42	138·3
	—	—	8·5	394·9	9·72	72·6
Mean	—	—	9·80	569·8	9·41	101·44

77–78b →

77–78a

* The copper and iron values on liver and kidneys are expre
whole blood. Haemoglobin expressed in grams per 10
From the above table it will be seen that material was collec
severe symptoms which varied from slight ataxia to pro

APPENDIX I.—*Table of Work done on the Farm Witteklip and Grouped according to the Age of the*

Group.	Foeti and Lambs,					
	Blood.		Liver.		Kidney.	
	Hb.	Cu.	Cu.	Fe.	Cu.	Fe.
A. Foeti.....	8·72	0·40	9·1	1,915	2·9	53.0
	8·00	0·42	8·2	786	4·3	21·9
	11·00	0·36	7·6	957·3	1·8	19·6
	6·01	0·34	8·9	1,688	3·7	75·8
Mean.....	8·43	0·38	8·45	1,338·6	3·2	42·6
B. Lambs at Birth....	—	—	—	—	—	—
	—	—	—	—	—	—
	—	—	10·9	1,981	2·9	72·6
	—	—	—	—	—	—
	—	—	—	—	—	—
	11·71	0·32	8·2	1,788	5·7	92·8
Mean.....	11·71	0·32	9·55	1,885	4·3	82·7
	9·71	0·18	5·62	3,111	1·8	443
	9·87	0·20	5·15	3,709	2·7	580
	7·80	0·15	5·43	1,684	2·1	320
	9·02	0·22	5·64	2,430	2·9	283
	11·00	0·16	6·91	2,156	1·65	231
	10·36	0·14	6·31	4,714	1·38	457
	10·71	0·16	4·64	6,237	2·25	728
Mean.....	9·78	0·17	5·67	3,434	2·11	434·5
C. Lambs about 1 Week Old	8·15	0·28	7·34	1,943	2·92	473
	9·50	0·32	7·56	2,780	3·13	541
	11·00	0·30	8·72	1,293	2·18	323
	—	—	—	—	—	—
Mean.....	9·55	0·30	7·87	2,005	2·74	446
	9·16	0·10	5·35	4,832	5·48	691
	10·36	<0·10	7·44	5,403	4·73	651
	7·09	<0·10	2·20	641	3·18	219
	6·0	<0·10	6·40	1,206	2·34	273
Mean.....	8·15	<0·10	5·35	3,018	3·93	458·5
D. Lambs about 2 Weeks Old.	10·5	0·20	8·92	1,720	3·75	218
	11·48	0·38	9·42	1,281	4·28	385
	9·79	0·35	12·62	2,020	2·92	428
	9·71	0·30	6·59	1,491	2·85	194
	—	—	—	—	—	— }
	—	—	—	—	—	— }
Mean.....	10·37	0·31	9·39	1·628	3·43	306
E. Lambs about 3 Weeks Old	10·11	0·20	6·57	5,977	4·97	1,948
	9·71	0·38	11·32	1,911	6·54	283
	8·90	0·50	10·46	1,243	5·82	107
	9·87	0·24	8·72	1,782	4·32	59
	7·80	0·16	5·46	3,462	2·46	493
	—	—	—	—	—	—
	—	—	—	—	—	—
Mean.....	9·28	0·29	8·50	3,055	4·82	578
F. Lambs about 1 Month Old	10·20	0 34	9·87	1,874	5·84	229
	9·80	0·40	9·02	1,242	7·66	308
	9·54	0·36	8·72	893	3·92	117
	—	—	—	—	—	—
Mean.....	9·85	0·37	9·20	1,336	5·80	218
G. Lambs about 6–8 Weeks Old	12·63	0·28	8·07	1,095	6·54	97
	9·57	0·20	3·79	2,237	1·55	252
Mean.....	11·1	0·24	5·93	1,666	4·04	175
H. Healthy Ewes and Lambs from the Farm Skuitjiesklip	—	—	10·23	3,258	9·42	278·2
	—	—	13·29	2,016	10·57	357·4
	—	—	10·87	2,561	11·64	620·4
	—	—	26·93	3,557	14·42	153·5
	—	—	11·34	3,480	10·38	218·7
Mean.....	—	—	14·53	2,974	11·28	325·6

77-78a ← 77-78c →

iron values on liver and kidneys are expressed in parts per million on absolute dry basis. The copper value for blood is expressed
Haemoglobin expressed in grams per 100 cc.
able it will be seen that material was collected from 58 animals, of these 18 were ewes, 35 lambs and 5 foetuses. Twenty of the lambs
oms which varied from slight ataxia to prostration, All the lambs showing symptoms are marked with asterisks. One ewe (X) sho

rding to the Age of the Lambs.

REMARKS.
Foetus nearly full time. Foetus nearly full time. Foetus nearly full time. Foetus nearly full time.
Lamd was placed in formalin. Contaminated with copper. Ewe was only bled. Lamb was placed in formalin. Contaminated with copper. Ewe was only bled. Lamb born and died during night. Material collected 6.6.41. Lamb born and died during night. Material collected 7.6.41. Material of lamb useless for histological purposes. *Lamb showed slight symptoms in hind limbs.
*Lamb showed marked symptoms of disease. *Lamb showed marked symptoms of disease. *Severe symptoms but less marked than above. *Symptoms less marked than above, able to rise. *Severe symptoms of disease, unable to rise. *Symptoms not quite as severe as above. Moves head. *Symptoms not quite as severe as above. Holds head up.
Ewe died, lamb showed slight symptoms in hindquarters. Lamb showed no symptoms; slight increase of fluid in cranium. Lamb showed nothing unusual except some dermatitis. *Slight symptoms in forelimbs.
*Lamb showed distinct sign of ataxia. Unable to keep balance, somersaults. Ewe only bled. *Distinct signs of ataxia. Walks with hind limbs sideways. *Severe symptoms. Lamb lies prostrate. *Distinct signs of ataxia in hindquarters.
*Slight ataxia in hind limbs, myosis and dermatitis. Lamb shows nothing unusual except some dermatitis. *Lamb well grown, slight ataxia in hind limbs. Lamb appears to be normal. Lambs appeared normal. Both not killed.
*Lamb weak, knuckles over in hind fetlocks and falls on side. Retarded growth, poor condition and myiasis in lamb. Lamb apparently healthy, shows no symptoms. Lamb apparently healthy. No symptoms. *Slight symptoms in hindquarters. Lamb shows no symptoms. Ewe and lamb not killed. Lamb shows no symptoms. Ewe and lamb not killed.
Lamb apparently healthy, shows no symptoms. Lamb apparently healthy. No symptoms noted. XEwe slight signs of ataxia. Lamb no symptoms noted. Lamb no symptoms noted. Ewe and lamb not killed.
*Lamb in good condition. Marked symptoms of ataxia when driven. *Lamb in good condition and well grown. Signs of ataxia when forced to run.
Lamkruis has never been known to occur on this farm.

77-78b

←

value for blood is expressed in parts per million

etuses. Twenty of the lambs showed either slight or asterisks. One ewe (X) showed slight symptoms.

77-78c